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SCREW MACHINES 2022
7-8 September DORTMUND, GERMANY

Programme
Book of Abstracts

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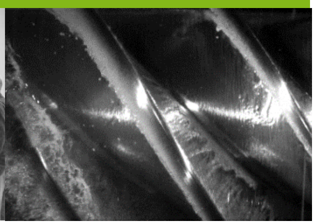

FOREWORD

Dear friends of screw machines,

Welcome to the 11th International Conference on Screw Machines (ICSM 2022) at the TU Dortmund University. Whether screw spindle or vacuum pump, screw compressor or expander, experts from industry and research institutions meet here to get to know about the latest developments and research findings. I am particularly pleased that, despite the pandemic, we will once again be able to meet in person at ICSM 2022, which - in addition to the technical information - will also enable us to build up and expand personal relationships.

I would especially like to welcome Dr.-Ing. F.-J. Peveling and Prof. J.-G. Persson as honored guests at this year's ICSM. Mr. Peveling has already been a speaker at the first "Schraubenmaschinen-Tagung" in 1984 and has been a lecturer at the TU Dortmund University for several years. Mr. Persson has been a speaker at the second "Schraubenmaschinen-Tagung" in 1987 and will again enrich this year's conference with his own paper.

Four years have flown by again! At the last conference in 2018, we could present the world's first tested dual-lead screw compressor as a highlight. From my point of view, a highlight of this year's conference is a transparent industrial screw compressor with oil injection, with which the distribution of the oil in the entire machine can be visualized for the first time via high-speed videos. Furthermore, I am convinced that the many other exciting contributions at this conference will also provide you with new insights into the state-of-art on screw machines. As usual, the papers of all past conferences are available for free download on the conference homepage (www.icsm.tu-dortmund.de). In addition, all papers of the current conference are published in the open access IOP (Institute of Physics) conference series.

Finally, I would like to thank all authors and attendees for their active contribution to the conference. I would also like to thank our sponsors, PTG Holroyd and Kapp Niles, whose financial support has helped to keep the conference fee constant. Furthermore, I would like to express my special thanks to the entire team of the Chair of Fluidics, especially Mrs. Ilona Kokott, Mr. Manuel Grieb and Mr. Kevin Weidler. It is only through their tireless engagement and personal efforts that the conference is made possible the way it is.

Prof. Andreas Brümmer
Conference Chair

WEDNESDAY 7 September 2022

Time	Session	
09:00	CONFERENCE REGISTRATION	
10:00	OPENING SESSION Room H.001 p. 3	
12:10	LUNCH BREAK	
13:30	NEW DESIGNS Room 1.001 p. 4	GAP FLOWS I Room 2.008 p. 5
14:30	COFFEE BREAK & LABORATORY TOURS	
16:30	ROTOR PROFILE AND CONTACT Room 1.001 p. 6	GAP FLOWS II Room 2.008 p. 7
18:15	CONFERENCE DINNER – sponsored by PTG Holroyd Machine Tools & Components Storckshof, Ostenbergstr. 111, 44227 Dortmund	

THURSDAY 8 September 2022

Time	Session	
08:30	SIMULATION & EXPERIMENT I Room 1.001 p. 8	SCREW PUMPS Room 2.008 p. 9
10:00	COFFEE BREAK	
10:30	SIMULATION & EXERIMENT II Room 1.001 p. 10	PULSATIONS & NVH Room 2.008 p. 11
12:00	LUNCH BREAK	
13:30	SCIENCE UPDATE (presentation only) Room 1.001 p. 12	SIMULATION & EXPERIMENT III Room 2.008 p. 13
	CLOSING SESSION ROOM H.001	
16:00	END OF THE CONFERENCE	

WEDNESDAY 7 September 2022

OPENING SESSION
Room H.001
Chaired by A. Brümmer

10:00 **Welcome address**
M. Bayer, president TU Dortmund University,
M. Rabe, representative for the Faculty of Mechanical Engineering & head of Department IT in Production and Logistics;
A. Brümmer, general chair & head of Chair of Fluidics
TU Dortmund University, DE

10:30 **Hydrogen as multivalent energy carrier – also for mobility?**
T. von Unwerth, Head of Department of Advanced Powertrains
Chemnitz University of Technology, DE

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11:20 **Improving vapor compression system efficiency through advanced vapor compression technologies**
E. A. Groll, Head of Mechanical Engineering
Purdue University, US

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WEDNESDAY 7 September 2022

NEW DESIGNS
Room 1.001
Chaired by M. Heselmann

13:30 **Design and analysis of conical rotary compressor**
Y. Lu et al.
Vert Rotors, UK
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14:00 **Systematic engineering design approach for improvement of oil-free twin-screw compressors**
T. Plantegenet[1] et al.[1,2]
[1] City, University of London, UK
[2] Howden Compressors, UK
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WEDNESDAY 7 September 2022

GAP FLOWS I
Room 2.008
Chaired by M. Grieb

13:30 **Laser-optical shear-flow analysis across the annular gap of a simplified displacement compressor model**

R. Leister[1], A. Brümmer[2] and J. Kriegseis[1]
[1] Karlsruhe Institute of Technology (KIT), DE
[2] TU Dortmund University, DE

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14:00 **One-dimensional calculation approach for gaseous clearance flows**

T. Jünemann[1] and A. Brümmer[2]
[1] Flowserve Dortmund GmbH & Co KG
[2] TU Dortmund University, DE

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WEDNESDAY 7 September 2022

ROTOR PROFILE AND CONTACT
Room 1.001
Chaired by C. Lehr

16:30 **Numerical investigation of contact loads of unsynchronized, dry-running screw machines**

D. Aurich and A. Brümmer
TU Dortmund University, DE

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17:00 **Contribution of modern rotor profiles to energy efficiency of screw compressors**

S. Patil[1,2] et al.[1,2]
[1] City, University of London, UK
[2] Kirloskar Pneumatic Company Limited, IN

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WEDNESDAY 7 September 2022

GAP FLOWS II
Room 2.008
Chaired by F. Nal

16:30 **Investigation of radial gap size change under load and the impact on performance for a twin screw compressor using numerical simulation**

R. Andres, J. Hesse and A. Spille
CFX Berlin Software GmbH, DE

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17:00 **Analysis of the flow through the blowhole of twin-screw machines with different rotor profiles using dimensionless numbers**

M. Heselmann and A. Brümmer
TU Dortmund University, DE

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THURSDAY 8 September 2022

SIMULATION & EXPERIMENT I
Room 1.001
Chaired by M. Grieb

08:30 **Design parameter study to extend the capacity range of dry twin screw compressors**

J.-G. A. Persson[1,2]
[1] JGP Teknikkonsult, SE
[2] KTH-Royal Institute of Technology, SE

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09:00 **Investigation of hydraulic losses in twin-screw machines**

M. Heselmann, H. Vasuthevan and A. Brümmer
TU Dortmund University, DE

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09:30 **Validation of inhomogeneous chamber states in rotary positive displacement vacuum pumps**

H. Pleskun, T. Jünemann and A. Brümmer
TU Dortmund University, DE

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SCREW PUMPS
Room 2.008
Chaired by C. Lehr

08:30 **Simulating the dynamic behavior of a triple screw pump without CFD**

S. Kosmann[1] et al.[1,2]
[1] Leistritz Pumpen GmbH, DE
[2] Siemens Industry Software GmbH, DE

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09:00 **Experimental investigations and 3D simulations by the overset grid method on twin-screw machines in both pump and turbine mode**

A. H. Moghaddam[1] et al.[1,2,3]
[1] Ruhr University Bochum, DE
[2] Klaus Union GmbH & Co. KG, DE
[3] ITT Bornemann GmbH, DE

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09:30 **Rheological modelling of viscoelastic fluid in a generic gap of screw pump**

S. Mehrnia et al.
Technische Universität Darmstadt, DE

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SIMULATION & EXERIMENT II
Room 1.001
Chaired by D. Aurich

10:30 **Conjugate heat transfer analysis of a twin-screw compressor with 4-6 configuration and internal cooling channels**

E.A. Groll[1] et al.[1,2]
[1] Purdue University, US
[2] Ingersoll Rand, US

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11:00 **Thermodynamic simulation and experimental validation of an oil-free twin-screw expander**

M. Grieb and A. Brümmer
TU Dortmund University, DE

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11:30 **Transient chamber filling in rotary positive displacement vacuum pumps**

H. Pleskun and A. Brümmer
TU Dortmund University, DE

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THURSDAY 8 September 2022

PULSATIONS & NVH
Room 2.008
Chaired by C. Lehr

10:30 **Use of CFD to optimize the design of a shunt pulsation trap (SPT) used for noise and vibration mitigation in oil free screw compressors**

J. Willie[1] et al.[1,2]
[1] CVS Engineering GmbH, DE
[2] Hi-Bar Blowers, Inc., US

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11:00 **Pulsating flow velocity profile measurement at an acoustically reflecting and non-reflecting open pipe end using Laser Doppler Anemometry (LDA)**

F. Nal and A. Brümmer
TU Dortmund University, DE

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11:30 **A novel screw compressor with a shunt enhanced compression and pulsation trap (SECAPT)**

J. Willie[1], P. X. Huang[1] and S. W. Yonkers[3]
[1] CVS Engineering GmbH, DE
[2] Hi-Bar MC Tech LLC, US
[3] Hi-Bar Blowers, Inc., US

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SCIENCE UPDATE (presentation only)
Room 1.001
Chaired by A. Brümmer

13:30 **CERES – industrial consortium for Compressors and Expanders in futuRe Energy Systems**
A. Kovacevic
City, University of London, UK
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Impact of surface structures on rarefied clearance flows
H. Pleskun
TU Dortmund University, DE
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Updates on development of internally geared screw machines
M. Read
City, University of London, UK
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Experiments with see-through screw oil-injected compressor
U. Dämgen
Boge Kompressoren, DE
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Challenges in measuring operational clearances in screw machines – project SECRET
T. Tam
City, University of London, UK
p. 58

Thermodynamic modeling of conical R718 screw spindle compressors with liquid injection
T. Mösch
TU Dresden University, DE
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THURSDAY 8 September 2022

SIMULATION & EXPERIMENT III
Room 2.008
Chaired by F. Nal

13:30 **A two-phase approach for simulation of water-flooded twin-screw machines validated for expander application**
A. Nikolov and A. Brümmer
TU Dortmund University, DE

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14:00 **On performance optimisation for oil-injected screw compressors using different evolutionary algorithms**
S. Patil[1,2] et al.[1,2]
[1] City, University of London, UK
[2] Kirloskar Pneumatic Company Limited, IN

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14:30 **Experimental and numerical analyses of the thermodynamic and mechanical performance of an oil-injected and economized 4/6 twin-screw compressor**
E. A. Groll et al.
Purdue University, US

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15:00 **Experimental research on influence of interstage oil injection in a dual-motor-driven two-stage screw air compressor**
X. Liao et al.
Xi'an Jiaotong University, CN

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OPENING SESSION

Hydrogen as multivalent energy carrier – also for mobility?

T. von Unwerth

Chemniz University of Technology, Germany

Many countries around the world are turning towards climate friendly energy usage. One of the main options appreciated is seen in electricity won from renewables and then used in a direct way for stationary and mobile applications. Taking into account that there's still a big lack for electric energy storage, hydrogen as an energy carrier more and more plays an important role. Producible via many different ways from almost any primary energy with different sizes of carbon footprints, it can be stored in large quantities, transported by pipelines, road or sea and can be used in a lot of applications. A selection of pathways for hydrogen as future energy carrier for mobility is presented and discussed.

Improving vapor compression system efficiency through advances vapor compression technologies

E. A. Groll

Purdue University, United States of America

The phase-out of ozone depleting and climate changing refrigerants as well as recent advances in compressor and other vapor compression component technologies, such as novel capacity control methods, use of smart sensors, materials and manufacturing practices, has rapidly increased the research efforts related to vapor compression systems for the HVAC&R industry. This presentation provides an overview of several research efforts related to novel compression concepts and unique cycle integration measures for refrigeration, air-conditioning and heat pumping applications with the goal to reduce irreversibilities and move system performance closer to Carnot efficiency. These research efforts include refrigerant injected compression with economization, near-isothermal compression with cylinder cooling and internal regeneration and rotor-cooled compression in twin screw compressors. The latest state-of-the-art of each of these research efforts will be introduced and discussed.

NEW DESIGNS

Design and analysis of conical rotary compressor

Y. Lu, K. Hoang, D. Noake and N. Low

Vert Rotors, United Kingdom

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Conical Rotary Compressor (CRC) is a screw type Positive Displacement Machine (PDM) consisting of one inner rotor rotating inside an outer rotor. The conical internal meshing rotors with the feature of variable pitch and rotor profile have an inherent capability to operation at high pressure ratio due to high built-in volume ratio and low leakage. CRC has potential to run in various applications such as Heating, Ventilation, and Air Conditioning (HVAC) system, vacuum pumps, and air compressors. The performance of the machine is heavily affected by rotor profile and rotor geometry. In this paper, non-parallel axis conical rotor is firstly introduced according to current successful design and manufacture practice, then parallel axis conical rotors are design based on meshing theory. Then, geometrical parameters such as meshing line length, cross section area, chamber volume and relative velocity are analysed. Finally, the experiments were conducted under different pressure ratio up to 26 and the volume flow rate, specific power, volumetric efficiency, and isentropic efficiency are compared. As a result of this study, CRC could maintain high level of volumetric and isentropic efficiency under wide range of pressure ratio. Improvement of the compressor design can be made to limit increases in temperature, reduce relative velocity and increase the overall efficiency of the machine.

Systematic engineering design approach for improvement of oil-free twin-screw compressors

T. Plantegenet[1], A. Kovacevic[1], S. Rane[1], A. Krupa[1], R. Leach[1], B. Patel[1], T. Tam[1], D. Lawson[2], M. Heiyantuduwa[2], B. Milligan[2] and J. Ure[2]

[1] City, University of London, Centre for Compressor Technology, EC1V 0HB, London, United Kingdom

[2] Howden Compressors, Old Govan Road, PA4 8XJ, Renfrew, United Kingdom

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Twin-screw compressors are widely used in industry, especially in compressed air, refrigeration, air-conditioning and process gas which consume a significant part of the world's energy. Nowadays, oil-injected compressors represent the majority of twin-screw compressors in the market due to their high efficiency and reliability. The oil-free compressor is potentially a better solution in the context of the net-zero CO2 target in 2050. However, due to its high thermal deformation and small clearances, this technology still suffers from reliability issues. To remedy this problem disruptive innovative solutions are required. In this purpose, the present study uses a systematic engineering design process to develop new concepts for the improvement of the oil-free twin-screw compressor. The paper is focused on the first two phases of the design process which are the definition of problem and the conceptual design. In the problem definition, main objectives are expressed and are divided into sub-objectives and weighed using an objective tree decomposition. Moreover, a thorough functional model of the oil-free compressor is detailed with a focus on the leakage paths and heat transfers. For the conceptual design, engineering characteristics extracted from the functional analysis have been assessed against the most important objectives using Quality Function Deployment matrices (QFD). Based on the developed problem definition, new concepts have been generated and three distinct concept categories have been further explored: Secondary flow; Surface features; Clearance control and monitoring. The evaluation, embodiment and detailed designs of the concepts, using experimental and numerical analyses will follow.

GAP FLOWS I

Laser-optical shear-flow analysis across the annular gap of a simplified displacement compressor model

R. Leister[1], A. Brümmer[2] and J. Kriegseis[1]

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[2] TU Dortmund University, Germany

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The present experimental feasibility study testifies the two flow measurement techniques Defocusing Particle Tracking Velocimetry (DPTV) and Interferometric Particle Imaging (IPI) for their applicability to measure the two-phase flow of thin (sub-millimeter) annular rotor-stator gaps such as occur across for the leakage flow e.g. in the housing gap of oil-injected rotary positive displacement compressors (RPDC). To provide unrestriced optical access to the annular gap and in turn eliminate secondary effects, a simplified displacement compressor model has been developed and fabricated from perspex. The proof-of-concept results of both experimental campaigns (DPTV & IPI) are discussed and avenues for future efforts towards a straight-forward and accurate applicability of either method are elaborated.

One-dimensional calculation approach for gaseous clearance flows

T. Jünemann[1] and A. Brümmer[2]

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Clearance flows do strongly influence the efficiency of dry-running positive displacement machines. To model the operation behaviour of the machines an accurate prediction of the clearance mass flows is crucial. If a chamber model simulation is used, the clearance mass flows are commonly estimate with simple equation to keep the computational effort low. Therefore, regression functions or coefficient databases are built into simulation. However, finding such functions or coefficients is a challenging and expensive task since many boundary conditions and geometry parameters must be varied in experiment or simulation. To reduce the effort of clearance analysis this paper presents a one-dimensional approach to estimate the clearance mass flow in e.g. dry-running screw-type compressors, based on the well-known differential equation of A.H. Shapiro for compressible flow of ideal gases. The friction is modelled with respect to laminar and turbulent flow. The flow separation and the friction of laminar flow are modelled based on the solutions of the Jeffery-Hamel flow. The friction in the turbulent regime is modelled by the Blasius expression, while the flow separation criteria is assumed to be the same as for laminar flow. The moving clearance wall is modelled assuming a superposition of Couette and Poiseuille flow. In addition, the heat transfer between gas and clearance boundary as well as gas rarefaction can also be optimally modelled. Results of the one-dimensional approach are compared to measurements and 3D-CFD simulations from the literature, varying Reynolds number and wall velocity.

ROTOR PROFILE AND CONTACT

Numerical investigation of contact loads of unsynchronized, dry-running screw machines

D. Aurich[1], A. Brümmer[1], A. Wittig[2], D. Stangier[2], W. Tillmann[2], C.-A. Thomann[3], A. Wittrock[3] and J. Debus[3]

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[2] TU Dortmund University, Institute of Materials Engineering, Germany

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Unsynchronized, dry-running screw machines have advantages compared to conventional oil-injected and synchronized, dry-running screw machines. Because of the absence of an additional timing gear and no injected lubricant, the effort for manufacturing and assembly can be reduced and lubricant residues in the process gas are avoided. In this design the female rotor torque is transferred directly to the male rotor by the contacting rotor surfaces. To investigate this contact, a two-dimensional boundary element method contact algorithm is developed to calculate the loads in terms of contact tractions and sliding velocities. The contact kinematics of the screw rotors and the non-constant curvature of the rotor surfaces are considered. The movement between the screw rotors is transformed into a relative coordinate system fixed on the male rotor. Furthermore, the influence of manufacturing tolerances to the occurring contact loads are investigated.

Contribution of modern rotor profiles to energy efficiency of screw compressors

S. Patil[1,2], M. Davis[1], N. Stosic[1], A. Kovacevic[1] and N. Asati[2]

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Screw rotors are the heart of screw compressors. And the energy efficiency of industrial machines is a matter of tremendous significance now more than ever. Historically, rotor profile developments have played a key role in making screw compressors energy efficient and commercially viable. Further attention to manufacturing aspects of rotor profiles and the invention of the rack generated rotor profiles led to rotor profiles having good manufacturability. The principles of rotor profile generation and manufacturing are available in open literature since 1960's. But more and more literature on rotor profiling has been published since then. Modern screw rotor profiles (patented close to and in the 21st century) have all the principles of a good profile incorporated in their design. Hence the industry and profile designers at large are aware of the increasing difficulty to further make the twin screw compressor rotor profiles more energy efficient. This paper tries to quantify the contribution of rotor profile to energy efficiency of a typical twin screw compressor by comparing the most recent (hence modern) screw compressor rotor profiles. In order to fairly compare different rotor profiles, all are retrofitted to a single size, lobe combination, rotor length, and helix angle. Only the curves constituting the profile, as dictated in the patent documents of the respective profiles, have been changed. Tools such as SCORPATH and SCORG have been used to do the geometric and thermodynamic calculations on the profiles. Keeping the working conditions same for all the retrofitted but different profiles, a comparison has been made. This comparison sheds some light on how much is the energy efficiency of a particular twin screw compressor influenced by a mere change of profile. This analysis can be further extended to establish reasonable targets for twin screw compressor manufacturers to improve energy efficiency of their machines via improving their rotor profiles. This remains the future scope of this work.

GAP FLOWS II

Investigation of radial gap size change under load and the impact on performance for a twin screw compressor using numerical simulation

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Computational Fluid Dynamics (CFD) and the Finite Element Method (FEM) are common and validated tools in research and industry for solving fluid flow or performing structural analysis respectively. Despite rather challenging, also the numerical simulation of screw compressors benefits from development and enhancement of numerical models, tools and methodologies. Differences between the real machine and the numerical model are inevitable, yet increasing accuracy and prognosis quality are desired by refining existing models and accounting for specific phenomena. Clearances within the working chamber (mainly intermesh clearance between rotors and axial and radial gaps between rotos and housing) strongly affect the flow characteristics, efficiency and thus the overall compressor performance. These clearances change under operating conditions because of thermal expansion or due to forces acting on the structure, whereas the clearance size is often only known for the reference state out of operation. The extent of deformation and the quantification of the resulting clearances is therefore of high interest in order to get the numerical model closer to real operating conditions. In this paper numerical simulation was used to determine the change in radial gap size between rotors and housing when the compressor is running and exposed to thermal and pressure loads. For a specific operating point, a 3D-CFD simulation for a 4-6 twin screw compressor with SRM profiles was conducted for the undeformed reference compressor geometry to calculate the flow field within the machine. Also, the temperature field within the housing and rotor solids was computed using the Conjugated Heat Transfer (CHT) method. The temperature and pressure fields were then submitted to the FEM solver to compute the deformation of rotors and housing. The results of this structural analysis served as input for a modification of geometry and numerical grids to account for the change in radial gap size. A re-run of the flow simulation in the deformed state enabled to quantify the impact on the machine performance and specific flow quantities. It could be shown that taking deformation into account, the volumetric efficiency is clearly affected. Commercial solvers from Ansys were utilized for solving fluid and structure. The spatial discretization of the fluid volume around the rotors was realized by employing pre-generated grids using the mesh generator TwinMesh. Here, there rotor deformation can

be defined in dependence of the axial position. The mesh of the housing maintained unchanged for all CFD simulations as a resulting gap size was determined by considering housing and rotor deformation relative to each other.

Analysis of the flow through the blowhole of twin-screw machines with different rotor profiles using dimensionless numbers

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To ensure safe operation, gaps in a screw machine are essential. Some are relatively easy to adjust, like front and housing gaps, while it is more difficult, if they depend directly on the selected rotor profile shape, such as the inter-lobe clearance and the blowhole. Consideration of mass flow rates through those clearances is crucial to predict operation conditions or design screw machines. When using chamber model simulations, it is common to calculate idealized, theoretical mass flow rates and to combine them with a flow coefficient which represents the effect of e.g. friction losses. This paper deals with the flow coefficient of the blowhole, which is formed by the two rotors and the housing cusp. Therefore, a set of dimensionless numbers is used, including physical and geometrical influences on the flow coefficient. The real mass flow rate of an ideal gas (e.g. air) through the blowhole is calculated by CFD-simulations. The dimensionless numbers are systematically varied to identify their specific influences on the gained mass flow rates.

Simulation & Experiment I

Design parameter study to extend the capacity range of dry twin screw compressors

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The possibility for extending the capacity range for oil-free dry twin screw compressors has been studied. Basic geometry parameters influence on compressor performance has been derived. The two parameters shaft speed and rotor diameter are critical. The lower capacity limit for dry screw compressors depends on maximum acceptable shaft speed, considering bearings, gearbox or power electronics. The higher capacity limit depends on rotor size, considering machining costs and tolerances for large rotor diameters. Thermodynamic efficiency and optimal rotor tip speed is dependent on internal throttling and leakage losses. Simplified analytical modelling has been applied, neglecting detailed geometry with minor influence on compressor performance. Basic kinematic relations give optimal shaft speed dependent on screw geometry non-dimensional specific displacement, on optimal tip speed (relatively constant independent of machine size), and on capacity. Basic kinematic relations also define the rotor diameter dependence on these three parameters, specific displacement; optimal tip speed, and capacity. The rotor profile geometry, i.e. number of lobes, rotor lobe depth/diameter, male tip width/diameter; as well as rotor length/diameter ratio and wrap angle determine the specific displacement. The specific displacement is non-dimensional and hence independent of the machine size or capacity. Also the specific internal leakage path lengths in the rotor mesh and between rotors and casing, as well as the specific outlet port size will be determined by the rotor profile major geometry parameters. Here specific means in relation to the male rotor diameter. A fixed internal pressure ratio (volume ratio) has been assumed. A simplified computerized model was developed to calculate the necessary geometry data and in particular the specific displacement and the optimal tip speed, from basic geometry parameters. For the case of constant specific clearances (independent of compressor size), the optimal tip speed is constant. For the case of constant absolute clearances, the optimal tip speed is slightly dependent on the compressor size. A simplified, non-female addendum, point generated, asymmetric profile was assumed. A cylindrical part of the male tip would allow a bigger outlet port while maintaining the built.in volume ratio. Rotor profile details with minor influence on performance have

then been omitted. The theoretical results from this study indicate that optimal compressor data should primarily be dependent on the number of male lobes and the lobe depth, i.e. the specific displacement. A screw profile with a lower number of lobes will result in a lower optimal shaft speed and should hence enable the design of dry screw compressors for lower capacity than the commonly used 4:6 lobe configuration. A screw profile with a higher number of lobes would result in a higher optimal shaft speed and in particular reduced rotor size (rotor diameter). It should hence enable the design of dry screw compressors for higher capacity than for the commonly used 4:6 lobe configuration, without having the machining problems of too large a rotor diameter. Considering also the efficiency, low capacity dry screw compressors with fewer rotor lobes, e.g. 2:4, might be the most promising option.

Investigation of hydraulic losses in twin-screw machines

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The wet-running twin-screw compressor is the most applied compressor type in industry. In these machines, an auxiliary liquid (e.g. oil or water) is injected into the machine. On the one hand, the liquid injection has advantages like the cooling of the compressed gas, the sealing of clearances, the lubrication of rotors and bearings and the reduced noise and vibration of the machine. On the other hand, the liquid injection shows hydraulic losses, which decreases the internal mechanical efficiency. A fundamental experimental model with an appropriate simulation model is presented to evaluate hydraulic losses. The experimental set-up consists of rotating male rotor profile within a cylinder, which is filled with air and a specific amount of water. Two-phase simulations are performed using the Eulerian method on a geometrical male rotor model based on the experimental set-up. Comparison of experimental and simulation results are performed regarding the impact of liquid amount on hydraulic losses and flow pattern of the water within the cylinder. A sufficient fit of the simulation to the experiment can be achieved with the shown approach.

Validation of inhomogeneous chamber states in rotary positive displacement vacuum pumps

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Chamber model simulation is a common approach to simulate rotary positive displacement vacuum pumps. Therefore the pump is abstracted into working chambers and connecting clearances, whereby the clearance leakages can be identified as the major loss mechanism in such machines. The clearance mass flow rates are calculated with respect to the thermodynamic states in the adjacent chambers, which are inhomogeneous for rarefied gases due to the movement of the rotors which causes a pressure gradient within the chamber. This effect increases with higher Knudsen numbers, because of the increasingly dominant friction. These inhomogeneous chamber states are assumed to be quasi-static in case that the chamber volume is constant with time. Therefore the chamber must not have a connection to the suction or discharge port. This can be modelled with a one-dimensional approach for geometrically abstracted chambers. In order to validate the one-dimensional characteristics in circumferential direction three-dimensional steady state simulations of a working chamber are performed using a Computational Fluid Dynamics (CFD) solver. To improve the accuracy for rarefied gases Maxwell velocity slip boundary conditions are applied. It is shown, that the inhomogeneous chamber states can be approximated by a regression analysis of a dimensionless number. Furthermore the housing clearance and the radial clearance mass flow rates for given boundary conditions are geometrically abstracted and calculated using a one-dimensional model. The new clearance models and the inhomogeneous chamber states are implemented in a chamber model simulation software and results of a test machine are compared to measurements and to previous simulations.

SCREW PUMPS

Simulating the dynamic behavior of a triple screw pump without CFD

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Pressure pulsations in screw pumps lead to noise, vibration and system strain. In order to increase the amount of dissolved and undissolved gas in the fluid while keeping noise, vibration and stress on the system at an acceptable level, the pump behavior must be understood in detail. Physical tests and CFD are common methods in modern pump design. However, both methods are not able to assess numerous design changes and machine integration challenges quickly. The system simulation approach tackles both challenges efficiently and allows to evaluate machine dynamics. Siemens Simcenter Amesim has been used to model a Leistritz Flexcore 45/90 triple screw pump. The model, containing components of a multi-physics library, calculates the movement of the chambers along the spindle package length by having virtual chambers alternately change their volume depending on the spindle rotation. Fluid properties, pressure dependent aeration and inertia effects are considered. The generation and displacement of the chamber volumes cause the suction and discharge of the fluid. The overlay of the single chambers results in the total volume flow of the pump. Internal leakage between the chambers is also considered, turning the model into a realistic digital twin of the screw pump. For the overall model and each individual chamber, the model gives volume flow rates, discharge pressure, pressure pulsation and internal pressure evolution. The air content has a significant influence on the pressure pulsations. To verify the model, measurements of operating points on a real pump have been carried out. Simulated volume flows and pressure pulsation show very good agreement with measurements. This new method for modeling screw pumps dramatically increases the speed of simulating pump behavior and opens the possibility of integrating the models into higher-level systems. The reproduction of dynamic effects and system responses for control tasks is also possible. The existing model can be extended towards further physics like friction modeling or additional system components like an electrical power unit.

Experimental investigations and 3D simulations by the overset grid method on twin-screw machines in both pump and turbine mode

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Twin-screw pumps due to their particular capabilities, offer unique benefits in comparison to other types of pumps. They can also recover wasted energy from the fluid system when run in a reversed way, i.e., in turbine mode. In this study, the possibility of benefiting twin-screw machines instead of conventional control valves in order to recover energy is investigated. Flow physics and energy recovery are analyzed experimentally and by 3D flow simulations in both, pump and turbine mode. Pump and turbine characteristics under different operating points are experimentally measured for low and high viscous fluids, i.e., water and oil, respectively. It is observed that for higher viscosity the dependency of volume flow rate on the pressure difference imposed on the pump is reduced. This observation indicates the significant effect of viscosity on the gap flow. Based on a simulation method by means of overset grid technique, unsteady 3D flow simulations with a high grid quality and a high spatial resolution particularly in gap regions in terms of $y+ < 1$ are conducted and results are validated against experiments. The profound assessment of gap flow based on the simulation results shows that for highly viscous fluids such as oil, the rotational speed of spindles as well as the direction of rotation have a significant effect on gap flow characteristics and consequently on the pump and turbine performance. From the experiments, it is clarified that with a lower rotational speed of spindles and a higher pressure difference, a higher amount of energy up to about 50% of the fluid energy in the piping system can be recovered instead of being dissipated by a conventional control valve.

Rheological modeling of viscoelastic fluid in a generic gap of screw pump

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In this study, the leakage of a non-Newtonian fluid, i.e. silicone oil, in a generic gap was numerically investigated. A CFD tool is used to determine the relationship between leakage flow, gap length and pressure difference. The investigated fluid is viscoelastic and its properties are modelled by a Maxwell equation. The Maxwell model can be used to precisely define the phenomenon of stress relaxation. Moreover, a comparison of the viscosity of measured data with simplified models shows that the Maxwell model has the best behaviour for viscosity prediction. Furthermore, at low pressures, leakage is reduced by decreasing the gap opening angle. However, this effect changes with increasing viscosity and relaxation time of the molecule. To determine the pressure drop, the Bagley diagram is used. The results show that as the shear rate increases, the elastic pressure drop values increase. In addition, the leakage current increases with an increasing slenderness ratio.

SIMULATION & EXPERIMENT II

Conjugate heat transfer analysis of a twin-screw compressor with 4-6 configuration and internal cooling channels

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Twin-screw compressor technology is widely employed in commercial and industrial HVAC&R applications as well as in air-compression and gas processing industries. Twin-screw compressors are characterized by relatively high efficiencies at part- and full-loads, and high reliability. However, innovative designs and higher efficiency are needed to further reduce power consumption, improve the compression process, and minimize internal losses. This study focuses on developing a simulation model of a twin-screw compressor with internal cooling channels to achieve a near isothermal compression process. A complex coupling between compression process and heat transfer occurs during the operation of the compressor. To analyze the compressor and the interaction between solid (i.e., rotors) and fluid phases (i.e., air and coolant), a CFD model with conjugate heat transfer has been developed and validated. The CFD model is used to predict compressor performance parameters such as isentropic efficiency, heat transfer rate, work input and pressure forces acting on the rotors. The performance of the twin-screw compressor with internal cooling channels is compared with a conventional twin-screw compressor.

Thermodynamic simulation and experimental validation of an oil-free twin-screw expander

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The chamber model method is still a powerful tool for the thermodynamic simulation of screw machines and is widely used in the industry and in science. When choosing adequate submodels for the compressible flows through machine clearances and the machine ports high simulation accuracy can be reached with minimal computation resources. However, detailed modelling is required when the complex geometry of twin-screw machines is abstracted to a zero-dimensional chamber model. In this paper a two-chamber model simulation tool is used for the thermodynamic simulation of an oil-free twin-screw expander operating with dry air as working fluid. Insights into the modelling process are presented and the importance of precise modelling of gap flows between adjacent capacities is discussed. The simulation results are finally validated against experimental data. Integral values obtained from the experiments, such as expander mass flow rate, indicated power, and effective power, are in good agreement with the numerical calculations. To gain a deeper understanding of the thermodynamics of the expander working cycle additional investigations are carried out at zero speed. The mass flow rates measured for a variation of stationary rotor positions are compared to values calculated with the two-chamber model method.

Transient chamber filling in rotary positive displacement vacuum pumps

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Chamber model simulation is a common approach to simulate rotary positive displacement vacuum pumps. Therefore the pump is abstracted into working chambers and connecting clearances, whereby the clearance leakages can be identified as the major loss mechanism in such machines. The clearance mass flow rates are calculated with respect to the thermodynamic states in the adjacent chambers, which are inhomogeneous for rarefied gases due to the movement of the rotors which causes a pressure gradient within the chamber. This effect increases with higher Knudsen numbers, because of the increasingly dominant friction. It is shown that inhomogeneous chamber states cause a non-complete chamber filling. As a result the mass-averaged pressure within the suction chamber is lower than the pressure in the suction port. Due to the non-constant chamber volume over time three-dimensional transient simulations with a Computational Fluid Dynamics (CFD) solver are performed in order to investigate the mass within a geometrically abstracted suction chamber. Based on a dimensionless number, a regression analysis is done to provide a quantitative estimation of this effect by means of analytical calculations. This is implemented in a chamber model simulation software and results of a test machine are compared to measurements and to previous simulations.

PULSATIONS & NVH

Use of CFD to optimize the design of a shunt pulsation trap (SPT) used for noise and vibration mitigation in oil free screw compressors

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Noise and vibration are problems that are inherent in screw compressors and other Positive Displacement (PD)Machines. This problem is driven partly by the lobe passing frequencies inside these machines that are generated due to the meshing between the gate and main rotors teeth. Because these compressors are operated over a wide speed range and at various loads they usually run at off-design conditions leading to either over or under-compression. In both scenarios, the pressure within the compressor always changes rapidly to match the discharge or process pressure when the discharge opens thus leading to pulsation and noise. To ensure that the compressor is operated without over and or under compression, which also negatively affects the compressor efficiency Hi- Bar Blowers, Inc developed a Shunt Pulsation Trap (SPT) that will contain and reduce the pulsation inside the compressor cavities thus eliminating the use of a silencer at the inlet and the discharge. During the SPT development the CVS Silo King (SKL 1100) compressor was selected for benchmarking this technology. CFD was used extensively to simulate the SKL 1100 without and with the SPT integrated, which allowed the SPT design to be optimized. This paper will present the results obtained to demonstrate that this technology has the potential to eliminate over and under compression while at the same time leading to energy savings and reducing the compressor footprint and the noise and vibration that are commonplace in screw compressors.

Pulsating flow velocity profile measurement at an acoustically reflecting and non-reflecting open pipe end using Laser Doppler Anemometry (LDA)

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Depending on the geometry and the operating conditions, occasionally strong and destructive acoustic resonances occur in the pipe spool (spool piece) between the high-pressure discharge of screw compressors and the following pulsation damper/silencer inlet. To avoid these resonances, the use of an orifice with a defined cross-sectional opening is investigated. By adjusting the orifice diameter as a function of the inlet Mach number, a non-reflecting end/transition can be provided. For a defined operating point, acoustic reflection from the orifice plate can be avoided in this way, thus preventing the acoustic resonance in the spool piece. Within the paper the pulsating flow field just downstream of the orifice is investigated using Laser Doppler Anemometry (LDA). For this purpose, the operating point-specific designed orifice is installed at the open pipe end of the air test rig at the chair of fluidics. By means of these LDA measurements, the velocity profile is determined experimentally downstream the orifice for the designed operation point and in off-design operation. The 2D measurement results (radial velocity and phase distribution) extend the results of the established 1D decomposition of pressure measurement signals into upstream and downstream traveling waves and allow a deeper understanding of the acoustic behavior of orifices.

A novel screw compressor with a shunt enhanced compression and pulsation trap (SECAPT)

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Some positive displacement (PD) compressors are equipped with automatic discharge valves such as reed valves that open automatically whenever the cavity pressure is slightly larger than the outlet pressure to deal effectively with varying pressure ratio applications. Screw compressors today do not have such valves, resulting in off-design conditions known as the under-compression or over-compression when the cavity pressure at discharge is deviating from the outlet pressure. Compressor efficiency suffers and pulsation/noise becomes worse under these conditions. Some type of controls are desired such as a discharge pulsation dampener or a variable volume ratio (often called variable Vi) slide valve design to lessen or cure the discharge pressure mismatch problems. Injecting gas vapor into a screw compressor cavity during internal compression phase has been known to be beneficial in enhancing compressor performance and has been widely used in HVAC&R industry known as the Economizer. However, the underlining principle of the Economizer has thus far not been explored for optimizing compression schemes of a screw compressor in general. This paper introduces a self-sensing and self-correcting compression process that can be “derived or deduced” from the Perfect Gas Law by optimizing for multiple design criteria such as compressor efficiency, pulsation/noise abatement, and cost and footprint reduction for a screw operating over a wide range of pressures. The scheme, called SECAPT (Shunt Enhanced Compression And Pulsation Trap), is then investigated and optimized numerically by a new CFD code for one industrial case: a bulk truck loading application where compressor pressure varies from no pressure rise to maximum load. The numerical simulations illustrate that SECAPT is tentatively capable of achieving multiple targets as theorized.

SCIENCE UPDATE
(presentation only)

CERES – industrial consortium for Compressors and Expanders in futuRe Energy Systems

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Through the Industrial Consortium CERES, City's Centre for Compressor Technology provides a forum for industry and academia to coordinate pre-commercial (TRL 1-3) research on industry-relevant compression and expansion technologies for the energy transformation sector. The Centre started this Industrial Consortium to create a network of partners for addressing global challenges by performing world-leading research in meeting Net-0 targets of compressor and expander future systems and expanding the scope of research by sourcing funds from research councils. Apart from the ongoing PhD studies from SECRET and IGSM, this year the Consortium is funding two new projects, namely: Project 1 - Artificial Intelligence tools for accelerated performance predictions and design in compressor systems and Project 2 - Lubricants for oil-injected positive displacement machines. With this presentation we would like to explore ideas from industry and academia attending ICSM conference on how can we enhance collaboration through this industrial consortium.

Impact of surface structures on rarefied clearance flows

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The reduction of clearance flows is crucial in order to improve the operation performance of vacuum pumps. One way to reduce these losses is to decrease the clearance height. Nevertheless, this procedure is limited by manufacturing tolerances, thermal expansion and general operation safety. Recent research results show, that for rarefied gas flows, there exists a huge potential in a different approach. As in rarefied gases the mass flow rate is dominated by surface collisions of the particles, one can manipulate their trajectories by applying a surface structure. This way, the clearance mass flow rates may be reduced without harming the operation safety.

Updates on development of internally geared screw machines

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Gerotor machines are commonly used as oil and fuel pumps, and as hydraulic pumps and motors. The mechanism consists of an inner and outer rotor which rotate in the same direction but are each centered about offset parallel axes. The rotor profiles are specified such that multiple continuous contact points occur between the rotors, demarcating separate working chambers whose volume varies from minimum to maximum and back to minimum during a single rotation of the outer rotor. For a gas or two-phase working fluid, varying the discharge port geometry allows internal compression to occur prior to discharge. Furthermore, adding helical twist to the rotors allows the forces and torques acting on the rotors to be modified in order to minimize contact forces and power transfer between the driven and idler rotors. This use of porting differs from other proposed configurations for internally-geared screw machines (IGSMs) dating back to the 1930s which focus on variations of profile or helix lead along the rotors to achieve internal compression. A current research project is investigating the performance and optimization of IGSMs for a range of compression applications. This talk will present progress made in comparing ported and un-ported IGSM configurations in terms of key geometrical features. The development of 1D chamber modelling and 3D CDF analysis tools will be discussed, and the design of experimental facilities for investigating the operation and performance of prototype machines will also be described.

Experiment with see-through screw oil-injected compressor

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In oil-injected screw compressors the efficiency is decided by leakage through the gaps between working chambers, friction losses and heat transfer between oil and gas. In order to have estimations about that, it is necessary to know the behavior of the oil in the working chambers and the gaps. There have been valuable experiments with small windows in the casing of an oil-injected compressor. But a full view of the oil behavior will show much more. So a screw compressor air end with a casing of glass was designed, and, after several difficulties due to the brittleness of the glass, started working. The work of recording high-speed films about the behavior of the oil has begun.

Challenges in measuring operational clearances in screw machines – project SECRET

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The size of operational clearances in rotary positive displacement machines is considered to be a critical parameter for their efficiency and reliability. Thermal loads are suggested to be the main source of clearance variation during the operation of an oil-free screw compressor, although the contribution of pressure loads and rotor displacements also add to the complexity of the non-uniform distribution of leakage gaps. Designers can size the clearances to ensure reliability, because their behavior is well understood in steady-state. However, the difficulty in minimizing these clearances to account for transient changes is limiting further optimization of compressor performance through the reduction of leakage flows. Therefore a clearance monitoring and control system is being developed as part of project SECRET (Smart Efficient Compression: Reliability and Energy Targets). This talk will present the requirements of an effective monitoring system, and highlight the challenges of the problem at hand. The presentation will conclude and open the discussion to possible solutions that could meet these requirements.

Thermodynamic modeling of conical R718 screw spindle compressors with liquid injection

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Water (R718) is a very challenging refrigerant in regards to the required volume flows and pressure ratios for chiller temperature ranges (6/12°C). A recent study shows that conical spindle screw compressors are able to combine high volume flows and high pressure ratios in one machine. This investigation focusses on the thermodynamic chamber model of the compressor including its internal leakage losses and its multi-port liquid injection. The results reveal the limits of the model and how the injection mass flow rate influences the internal leakage losses.

SIMULATION & EXPERIMENT III

A two-phase approach for simulation of water-flooded twin-screw machines validated for expander applications

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In the lower and medium power range, twin-screw machines offer a high potential for energy conversion in various compressor applications or with respect to electrical power generation from regenerative and exhaust heat sources, e.g. as expanders in Rankine cycles. With the aim of minimising internal leakages and lubricating moving machine parts, an auxiliary liquid can be applied to the working process. Furthermore, machine operation becomes more isothermal reducing thermal stress and providing advantages as for energy conversion. In this study, a two-phase approach for simulation of the operational behaviour of water-flooded twin-screw machines is presented. The thermodynamic fluid state is calculated by means of the humid air model considering the two-phase mixture in thermal equilibrium. Additionally, dissipative two-phase mass flow rates are predicted regarding a slip-flow model and two-phase discharge coefficients. The proposed two-phase modelling including liquid distribution in the working chamber is validated for expander applications considering available experimental data of the test twin-screw expander SE 51.2 in terms of indicator diagrams, indicated power, mass flow rate, and outlet temperature.

On performance optimisation for oil-injected screw compressors using different evolutionary algorithms

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Energy consumed for pressurizing air makes a significant proportion of total electrical energy consumption worldwide. To reduce the carbon footprint, it is necessary to have air compressors, which can operate efficiently over a large range of pressures and flow including full load and part load conditions. Several studies have been performed in this area including some which monitor the performance of a large number of compressors to develop strategies for their designs. This paper focuses on the design optimisation of geometrical and oil parameters of oil-injected screw compressors using different evolutionary algorithms such as genetic algorithm (GA), covariance matrix adaptation evolution strategy (CMA-ES), and so on. A comparison of the performance of these algorithms is presented. SCORG and GT-SUITE (commercial software tools for screw compressor thermodynamic simulations and optimisation) are used in the integrated model producing promising results. Feasibility of the optimum outcomes generated by these algorithms is critically evaluated from machine and system design point of view. Finally, in the context of optimisation presented here, the simplex converges fastest as compared to other algorithms. In the future study, the system design limitations are to be incorporated as constraints for the optimisation along with the objective to improve energy efficiency.

Experimental and numerical analyses of the thermodynamic and mechanical performance of an oil-injected and economized 4/6 twin-screw compressor

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To advance oil-injected twin-screw compressors, it is necessary to understand and model the complex physical phenomena occurring during the compression process (e.g., mass and heat transfer mechanisms) as well as analyze the mechanical behavior of the compressor (e.g., rotordynamics, bearing loads, variation of clearance gaps). To validate these models, the in-chamber compression process as well as mechanical loads need to be accurately measured. This paper presents a comparison between experimental results and numerical modeling of a 4/6 oil-injected twin-screw compressor with slide-valve part-load modulation and economization. The compressor has been equipped with high-frequency pressure sensors, load-cells at the bearings and torque sensor on the main rotor. Bearing forces are analyzed to quantify and validate the experimentally obtained axial force data. The validated model can later be used to analyze the mechanical performance of the compressor, such as bearing loss computation. This study also discusses isentropic and mechanical efficiencies computed for the various data points.

Experimental research on influence of interstage oil injection in a dual-motor-driven two-stage screw air compressor

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Energy saving for compressed air production is of great importance all over the world due to its great energy cost and the indispensable utility of compressed air in the industrial sector. In recent years, oil-injected two-stage screw air compressors, especially driven by dual motors, are becoming a promising alternative to other compression equipment for their extraordinary efficiency and high reliability in a wide range of applications. However, two-stage screw air compressors have a different and complicated oil injection system compared with single-stage compressors. And an appropriate setting of oil injection parameters might result in a considerable performance improvement of the compressor. In this paper, a dual-motor-driven two-stage oil-injected screw compressor was tested under the actual service conditions and control modes experimentally. The effect of interstage oil injection on the compressor performance was studied in detail by varying the interstage oil injection flow rate and rotating speed. The performance parameters such as specific power, volumetric efficiency and adiabatic efficiency were calculated from the measured data. The results indicate that an excess amount of oil exists in the second stage compressor and reducing the oil moderately could decrease the power consumption of the two-stage air compressor unit.

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