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Experimental and Numerical Study of Flow Dynamics in the Leakage Gaps of Oil-Free Positive Displacement Machines

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Extended Abstract

Rotary positive displacement machines are widely used in industry. Their efficiency is influenced by leakage through the clearance gaps between their stationary and rotating parts. The study of leakage flows through the clearances in oil-free rotary positive displacement machines (PDMs) is necessary to get a real insight into the attributes of such leakage flows. Computational fluid dynamics (CFD) can help in understanding the nature of leakage flow phenomena. But sufficient experimental results are needed to validate the CFD models. Example, it is extremely challenging to obtain the correct velocity field of the leakage flow in the running conditions of the machine. Therefore, this study focuses on the design and development of an experimental setup that can measure the velocity field with the controlled operating parameters of the machine. This study is a part of project SECRET (Smart Efficient Compression, Reliability and Energy Targets), which is supported by an award from The Royal Academy of Engineering, UK and Howden Compressors to City, University of London's Centre for Compressor Technology.

In this study, a Howden URAI-22 oil-free Roots blower is used. To have an optical access to visualize the flow field inside the machine, a metallic part of the casing is replaced by sapphire glass. National Instrument's hardware-based data acquisition system is designed to measure and control machine operating parameters such as pressure, temperature, flow, power, and speed by implementing appropriate sensors. The particle image velocimetry (PIV) technique is identified for velocity field measurement[1], and the setup is designed using optical components[2]. Designed experimental setup specifically consists of Litron Bernoulli laser (200-15), Long laser guide arm (532/266nm), Beam waist adjuster, HiSense Zyla sCMOS Camera 5.5MP, UV/VIS Parallel Light Sheet Optics (H 50mm at 532 nm), Performance synchronizer, Seeder, K2 Distamax lens with CF2 and CF4 objective, an imaging system with Dynamic studio software. Clearance flow field is obtained with experiments over the range of operating conditions (Speed and discharge pressure) of the machine.

PIV results were processed and data such as gas velocity, local flow patterns, turbulent kinetic energy and transient flow structures were then evaluated in a fully transient, three dimensional CFD model of the test Roots Blower. An important feature of this numerical model is the deforming computational grid required for the flow solver and this was obtained using in-house tool SCORG[3][4]. The boundary conditions at suction, discharge and the rotor operating speed were set as per the test data and the CFD model was used to analyse the resultant fluid flow and thermal field. Leakage gap flow and downstream pattern of local field were quantitively compared with the PIV measurements in order to verify the computational model which will be used further for design improvement and detailed evaluation of leakage reduction mechanisms.

References

[1] G. Singh, S. Sun, A. Kovacevic, Q. Li, and C. Bruecker, "Transient flow analysis in a Roots blower: Experimental and numerical investigations," *Mech. Syst. Signal Process.*, vol. 134, p. 106305, 2019.

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27th March 2023

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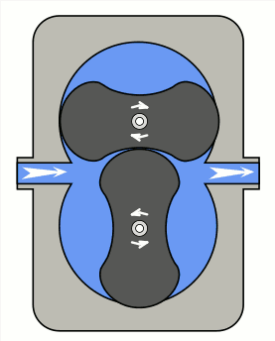
- Introduction
- PIV experimental measurement & results
- Simulation
- Conclusion

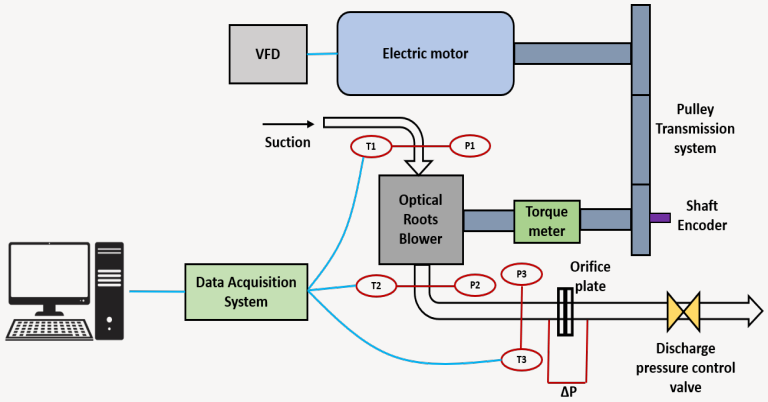
PIV : Particle image velocimetry

Introduction

- 10% of industrial electricity is consumed to produce compressed air. This figure grows up to 20% if other, non-industrial compressor needs are considered [1]. A System containing rotary machines greatly contribute to the majority of the carbon emissions.
- Rotary machines have a clearance gap between the rotating and stationary parts that create leakage flows. They largely affect the reliability and performance of the machine.
- This study focuses on leakage flows in the PDMs because it is one of the most influential factors on the efficiency of PDMs.
- Experiments were performed on Roots blower because it is a good representative of the rotary compressor.
- This study is a part of project **“SECRET” (Smart Efficient Compression, Reliability and Energy Targets)** supported by The Royal Academy of Engineering (RAEng) and Howden Compressors, UK.

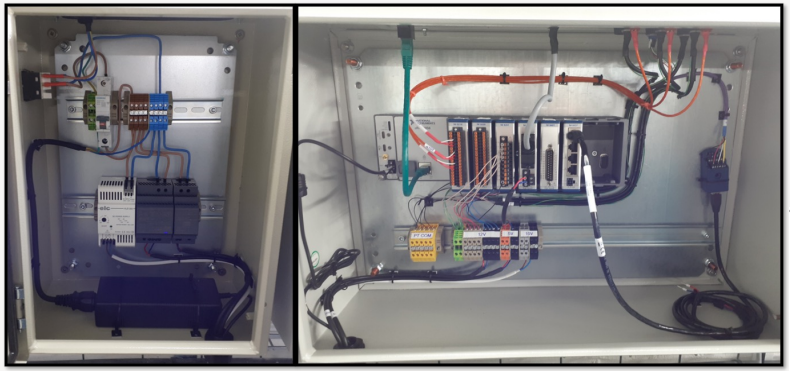


Optical Roots Blower test rig

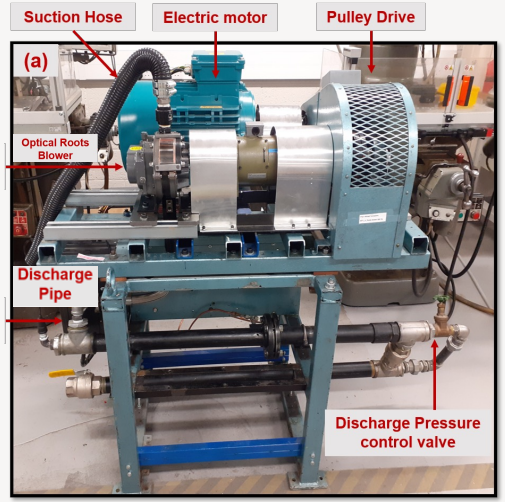


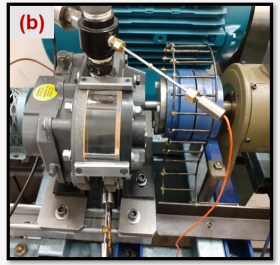
- Oil-free Roots blower URAI-22 from Howden

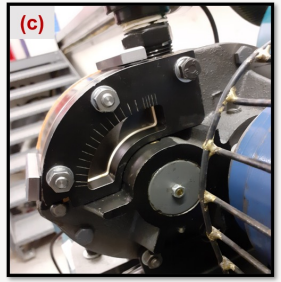
Schematic diagram of Roots blower test rig



DAQ system with Power supply unit





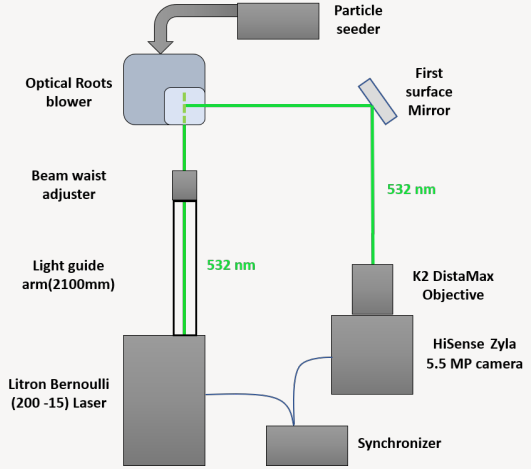


(a) Roots blower test rig (b) Optical access from top (c) Optical access from side

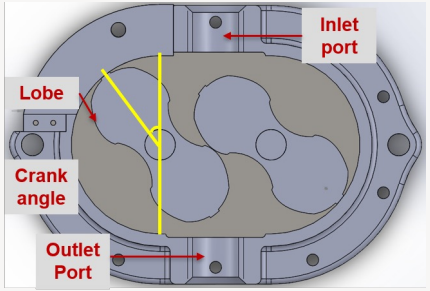
Parameters of the Roots blower

Items	Specification	Items	Specification
Diameter of the rotor [mm]	101.3	Tip gap[mm]	0.1
Axis distance [mm]	63.12	Interlobe gap[mm]	0.17
Rotor length [mm]	50.5	Axial gap[mm]	0.15
Displacement volume [l/rev]	0.4618	Width of tip step[mm]	6.4

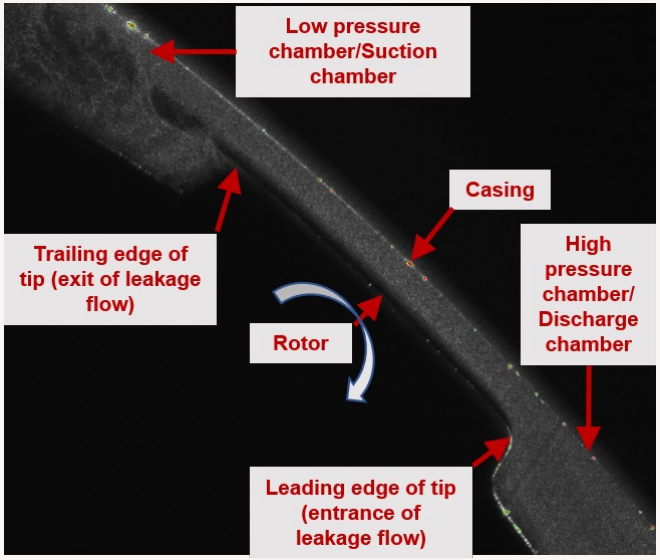
Particle Image Velocimetry (PIV)



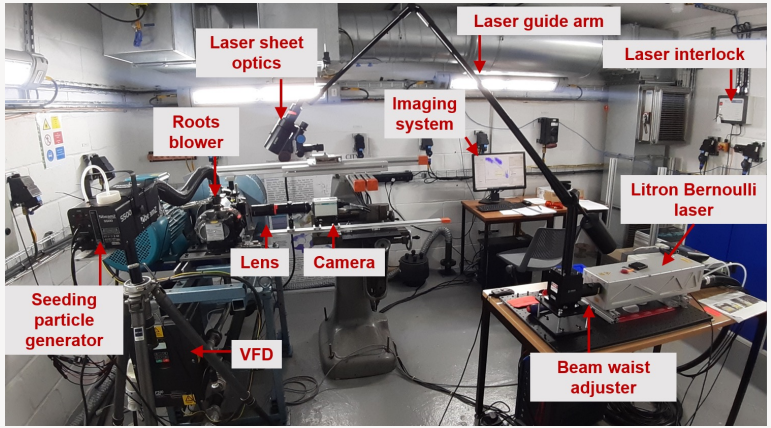
Schematic of PIV test setup



Rotor tip position (Radial clearance 0.4mm)



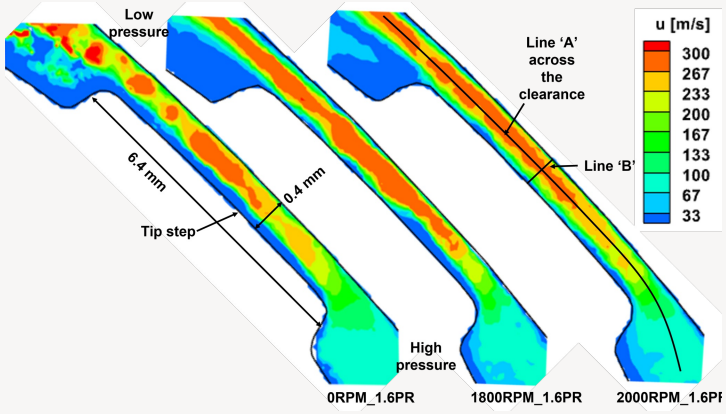
Raw image & Used terminology



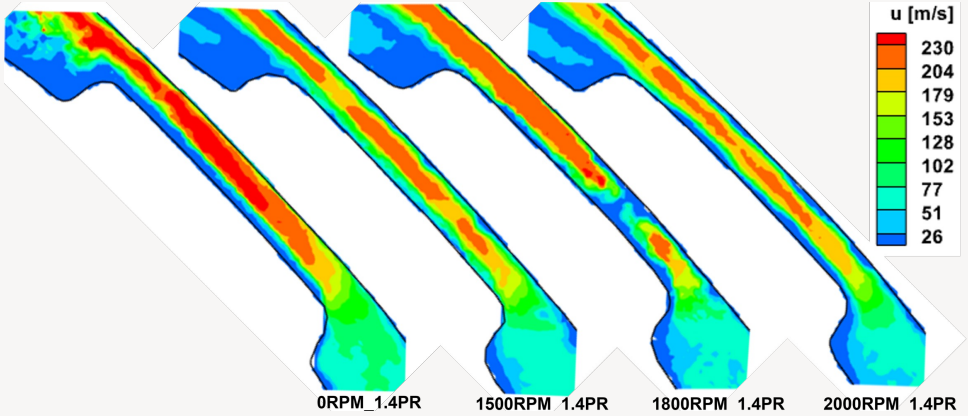
PIV test setup

- Measurements are carried out in **static** and **dynamic conditions.**

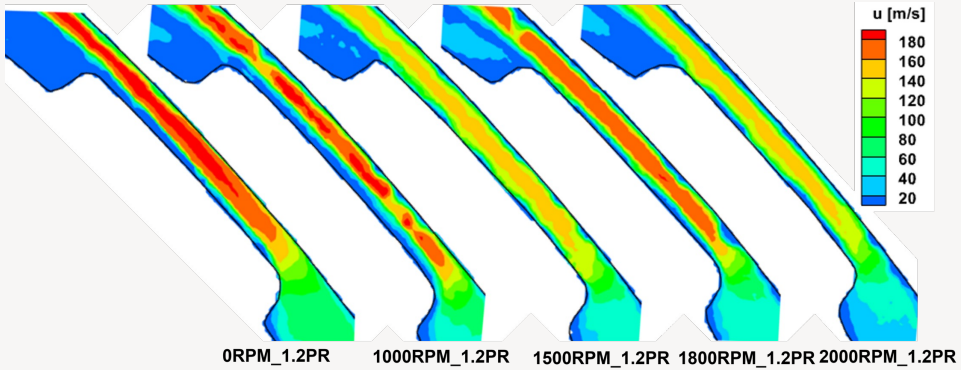
PIV results



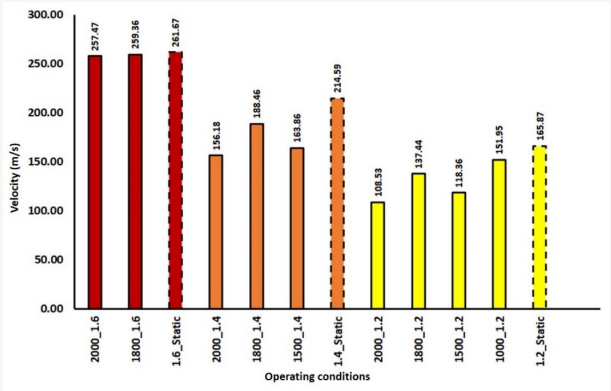
Velocity magnitude at 1.6 pressure ratio



Velocity magnitude at 1.4 pressure ratio



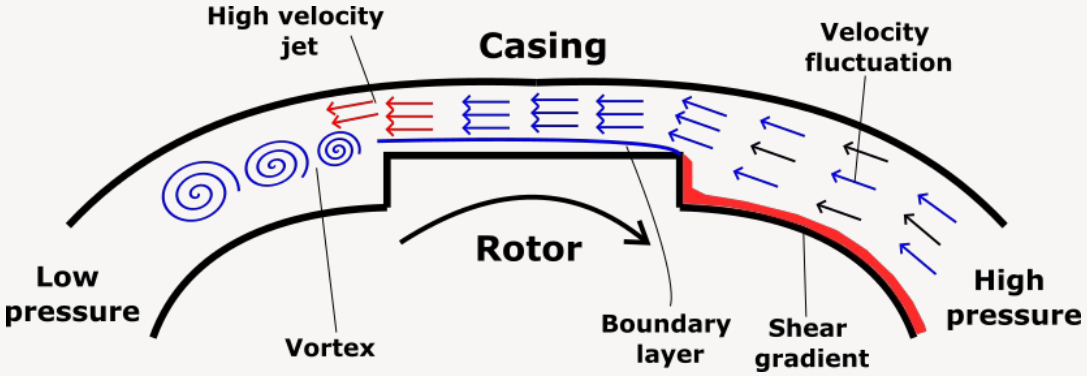
Velocity magnitude at 1.2 pressure ratio



Comparison of the average velocity in the clearance gap at all measured conditions

Findings from PIV measurement

- Average velocity in static conditions **>** Average velocity in dynamic conditions
- Average velocity in clearance is decreases with increase in the speed of rotor.
- Velocity is getting increased drastically when flow enters into clearance and it exit as a jet of air.
- At the entrance of the tip, flow separation is observed due to the very high velocity and a boundary layer is observed over the entire span of the tip without any reattachment.
- Vortices structure similar to ‘Kelvin-Helmholtz Instability’ are present, which grows in size as it moves away from the trailing edge.



Schematic of flow structures found from the measurement in leakage flows

Conclusion

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Thank you