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DESIGN AND VERIFICATION OF AN AIR ROTARY VANE EXPANDER

TAČR KAPPA DEXPAND – FINAL MEETING

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OUTLINE

1. Introduction to RVE

2. How to design RVEs - mathematical background

3. Air RVE – design details

4. Air RVE measurments and results

5. Conclusion & future work

1. INTRODUCTION TO RVE: GENERAL

- RVE = volumetric expander
- Simple working principle: Vanes inserted in radial slots in the eccentrically placed rotor, creating expanding chambers for working fluid
- LORCA (Laboratory of Organic Rankine Cycles and their Applications) @ UCEEB has many experiences with construction and testing RVEs especially for organic fluids

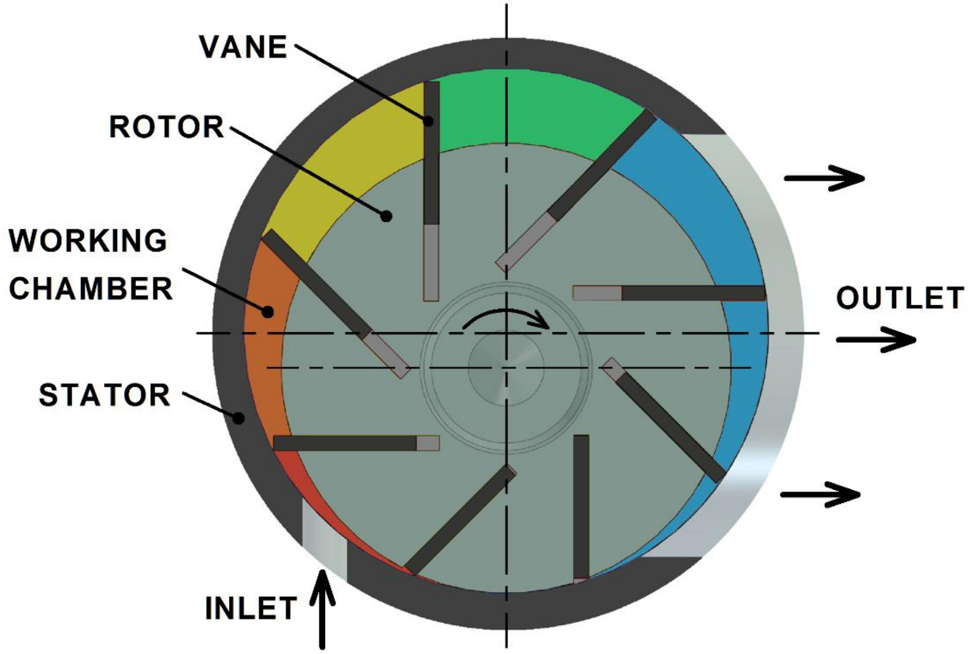

Fig. 1 Cross-section view of RVE

1. INTRODUCTION TO RVE: LORCA

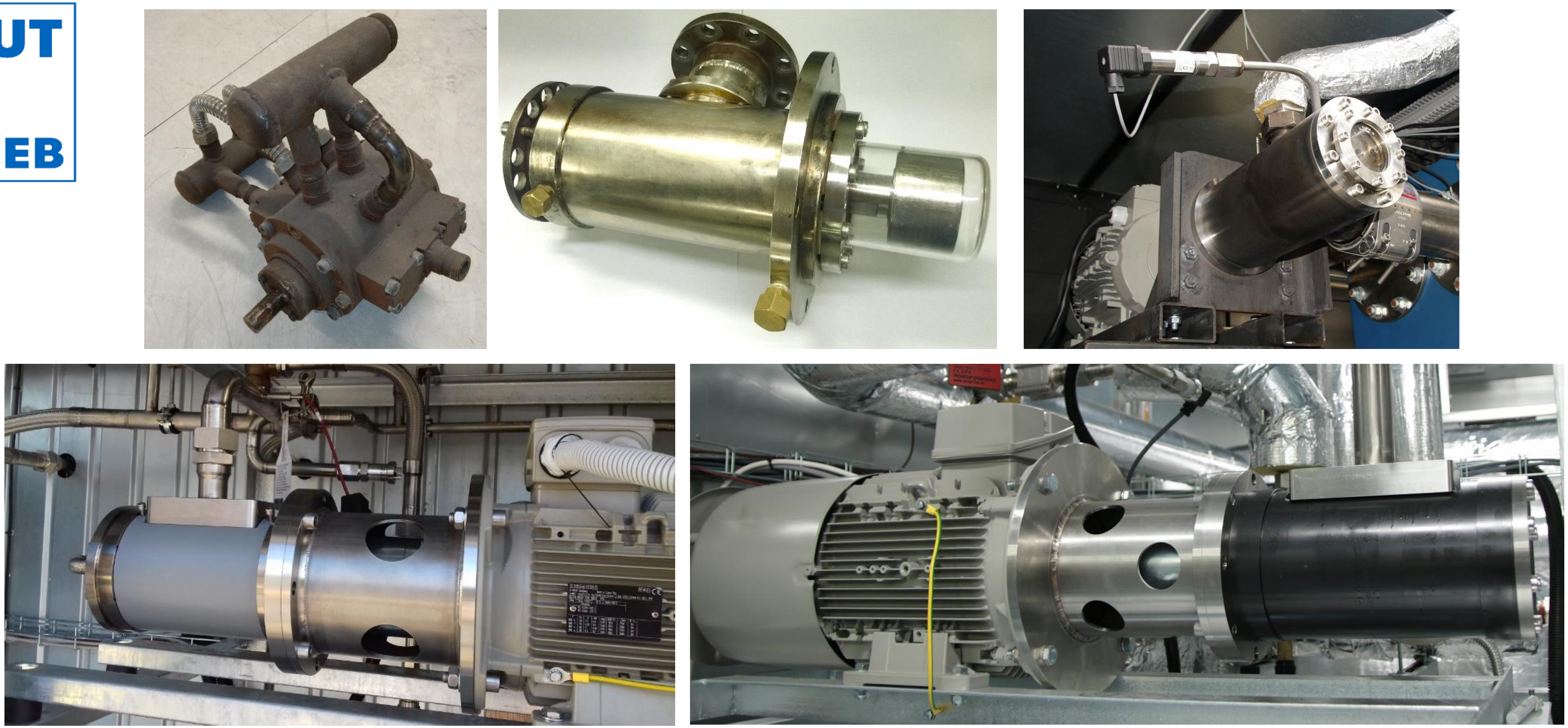

Fig. 2 Several RVE prototypes built at LORCA

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1. INTRODUCTION TO RVE: PROS & CONS

+ Low speed (direct connection with common generators without gearbox or need of high speed generators)
+ Simple construction and manufacturing, cheap (?)
+ Good performance to weight ratio
+ Ideal for low power applications (hundreds of watts to several kilowatts)
- Lower efficiency (friction losses, leakages)
- Possible lifetime issues (esp. vanes)

2. HOW TO DESIGN RVE?

- Based on good mathematical description:
- 2 main mathematical models:

1) 1D flow model based on mass and energy balance
2) Model of vane dynamics

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2. HOW TO DESIGN RVE?

1D flow model:

- Considers **real geometry with clearances** for main flow and leakage flow calculation
- Simple friction and heat loss model (**vane friction is not negligible**)
- Predicts p-V diagram -> power output
- Input parameters (geometry) can be optimized by GA

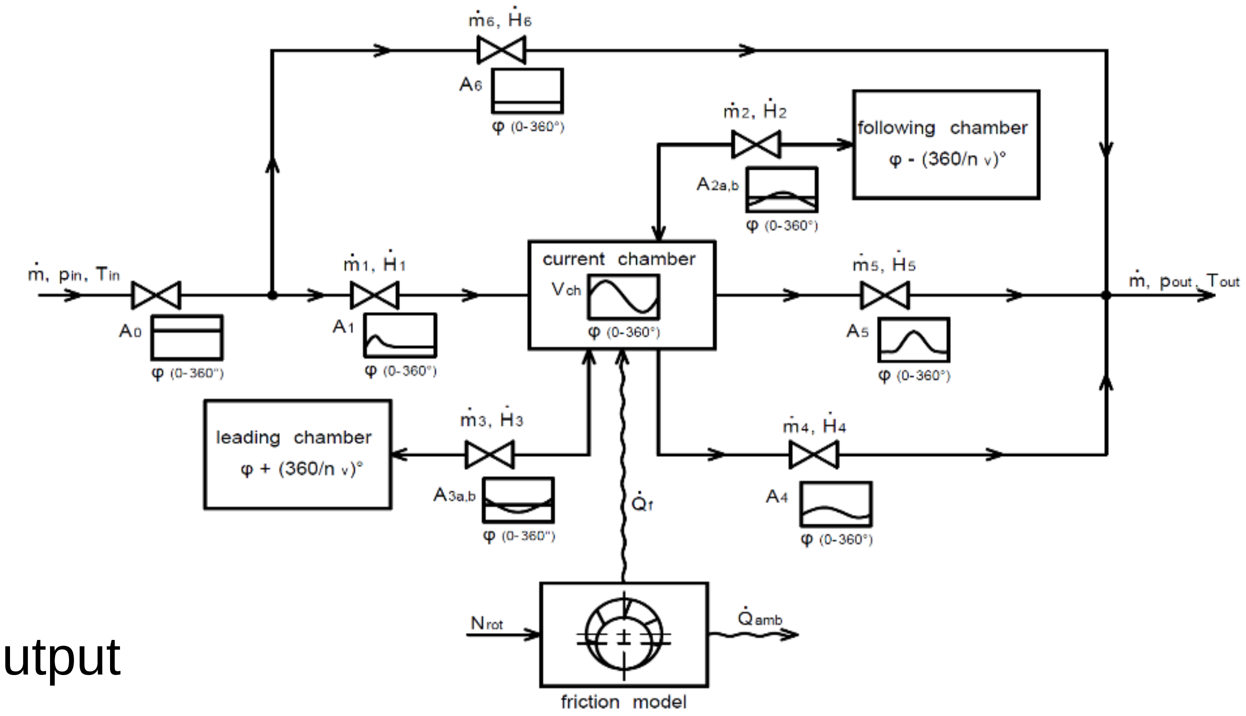


Fig. 3 Scheme of 1D flow model with a simple friction model

2. HOW TO DESIGN RVE?

Model of vane dynamics

- Improves simplified friction model
- Can predict loss of contact between vane and stator = excesive leakage
- Can predict vane stress (bending stress, contact stress..) -> important for practical design

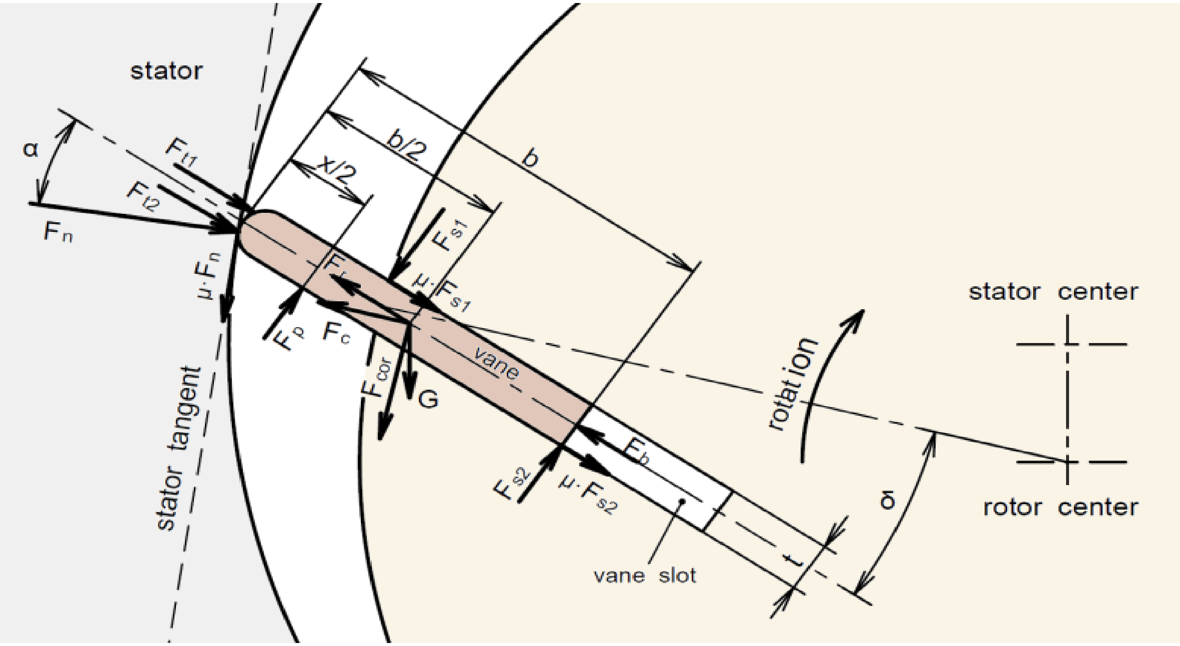


Fig. 4 Scheme of forces acting on a vane

2. HOW TO DESIGN RVE?

Typical model outputs:

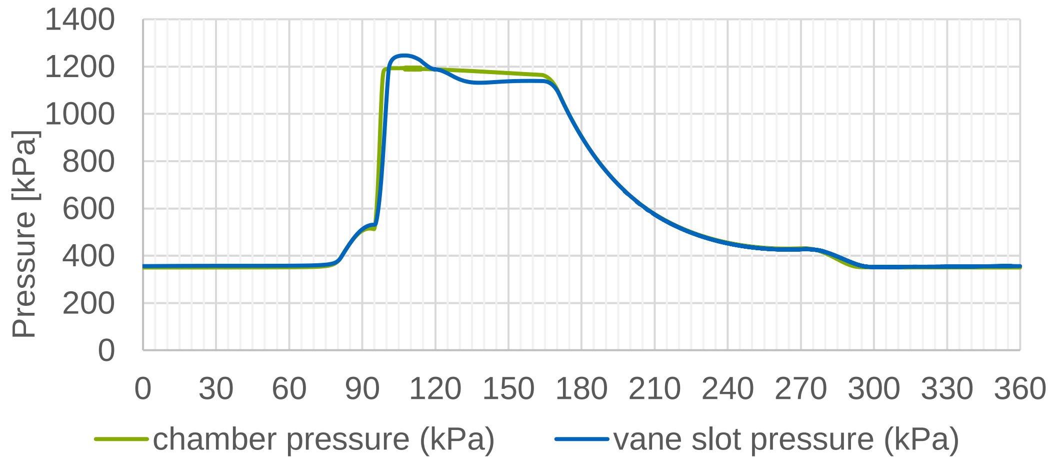


Fig. 5 Pressure – rotor angle diagram

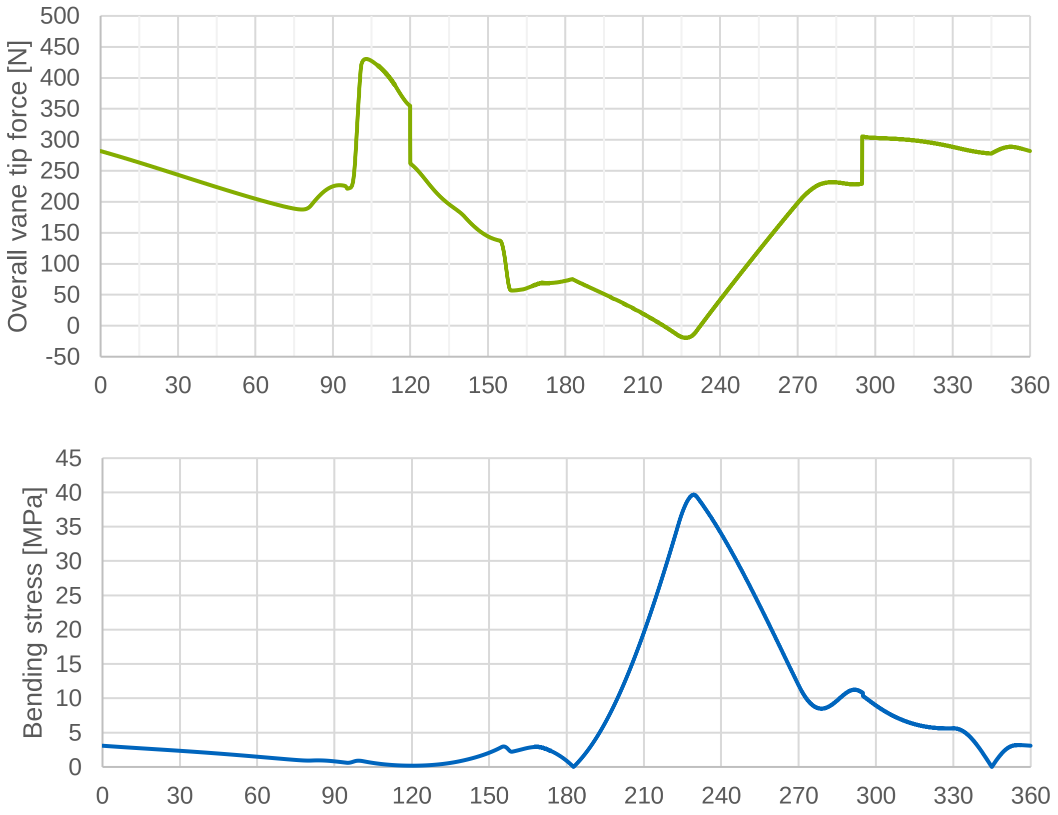


Fig. 6 Vane stress – rotor angle diagram

3. DESIGN OF AIR RVE: PARAMETERS

- Designed a small 1kW air RVE suitable for low-power applications

Parameters	Unit	RVE
Working fluid	-	dry air
Total inlet pressure	bar(a)	10
Inlet temperature	°C	40
Design volumetric flow rate	l/s	0.82
Static exit pressure	bar(a)	1
Stator diameter	mm	64
Rotor diameter	mm	55
Rotor length	mm	25
Rotational speed, n	rpm	3030
Nominal design expansion efficiency	%	48.2
Nominal design power output	kW	1

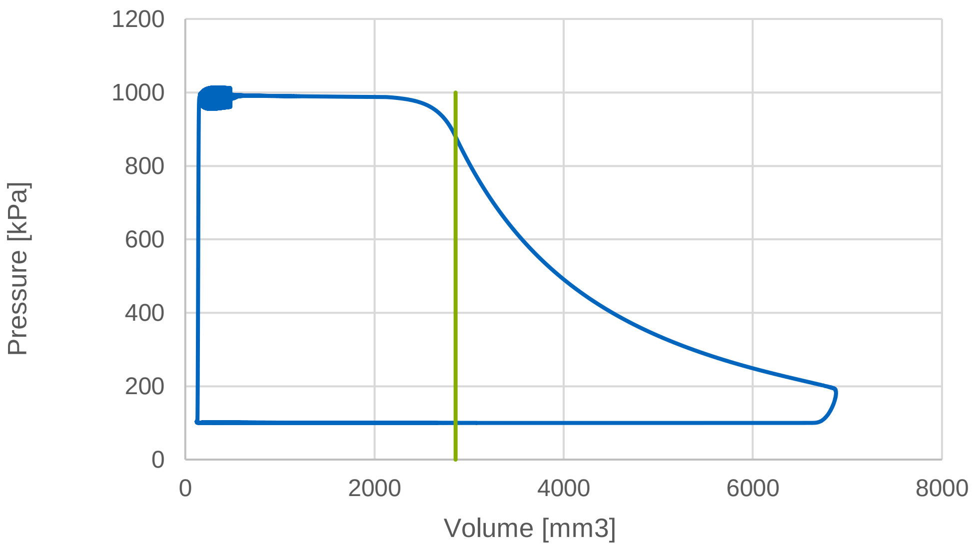


Fig. 7 Resulting pressure - volume diagram

- Due to model capabilities simple modification to other working fluids

3. DESIGN OF AIR RVE: ASSEMBLY & DETAILS

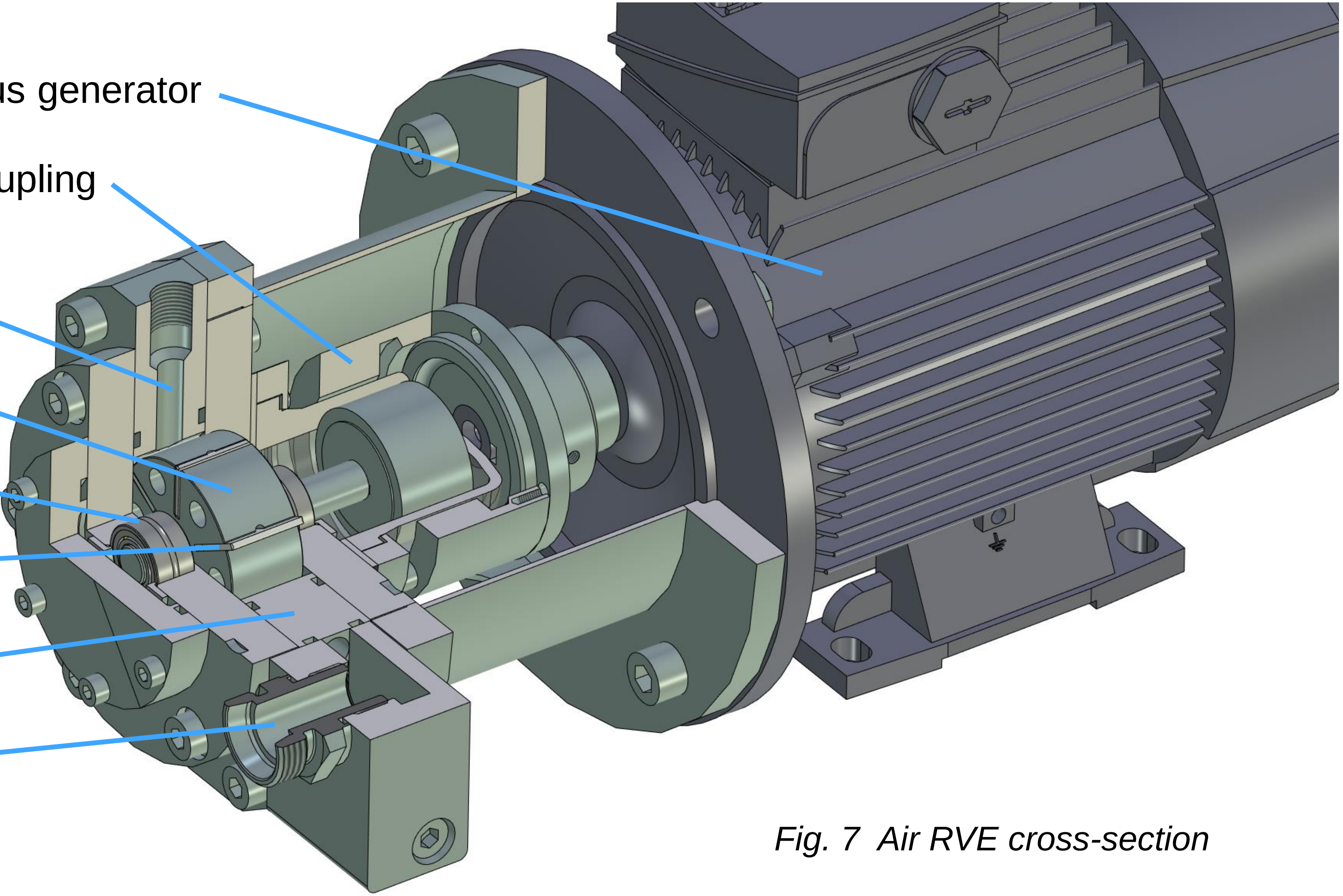


Fig. 7 Air RVE cross-section

3. DESIGN OF AIR RVE: ASSEMBLY & DETAILS

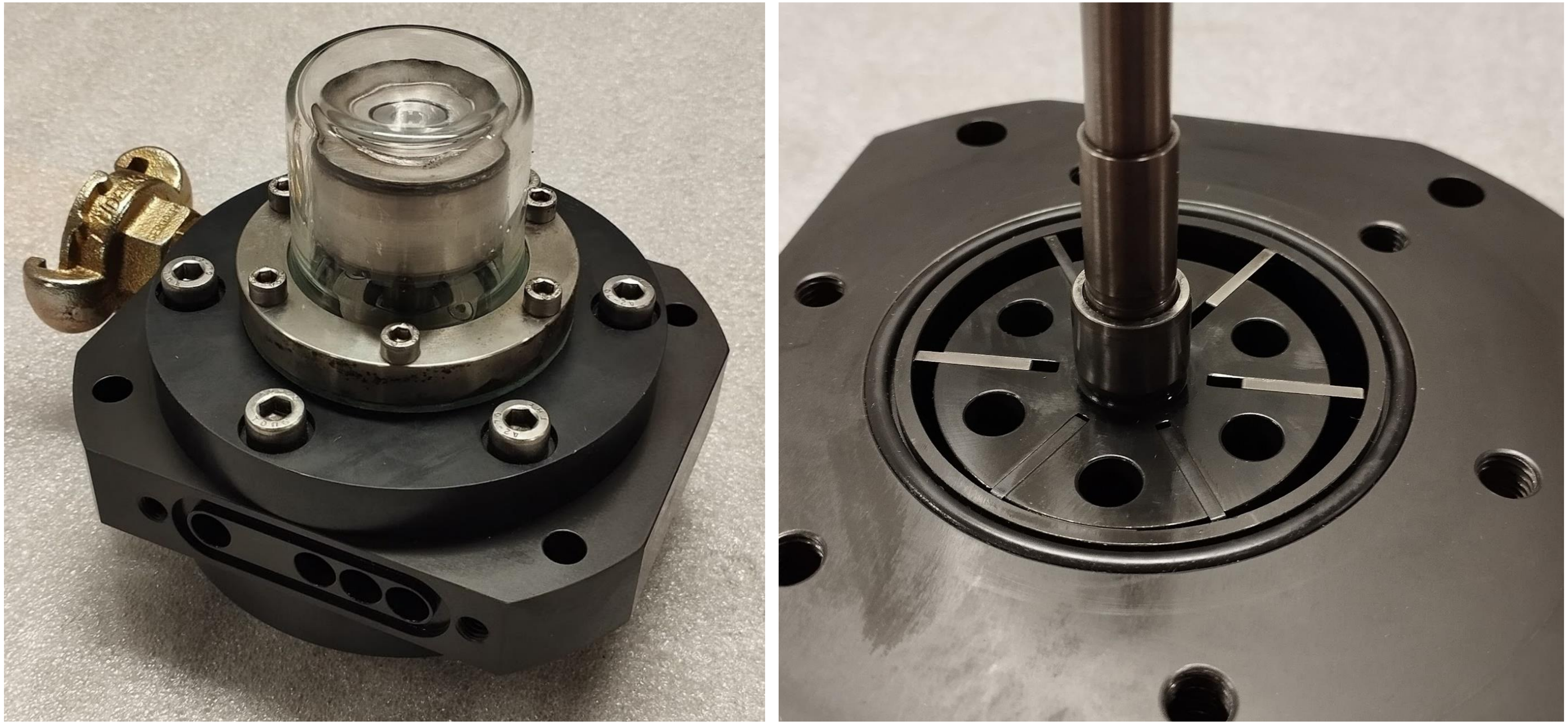


Fig. 8 Assembled air RVE

3. DESIGN OF AIR RVE: ASSEMBLY & DETAILS

- Correct function of vanes - steel vanes are needed (high mass = high centrifugal force)
- Capable of low-oil or even oil-free operation due to special DLC coating with MoS_2 (vanes and stator)
  - lifetime of vanes – subject of intensive research →
  (not only for air RVE)
- Hermetic design thanks to magnetic coupling – no leaks around the shaft

Fig. 9 Example of wear of a steel DLC coated vane

4. AIR RVE MEASUREMENT

- Performance and efficiency characteristics measured using compressed air and an electromagnetic brake
- Measurements confirmed large dependence on rotational speed (large leakages during filling phase)

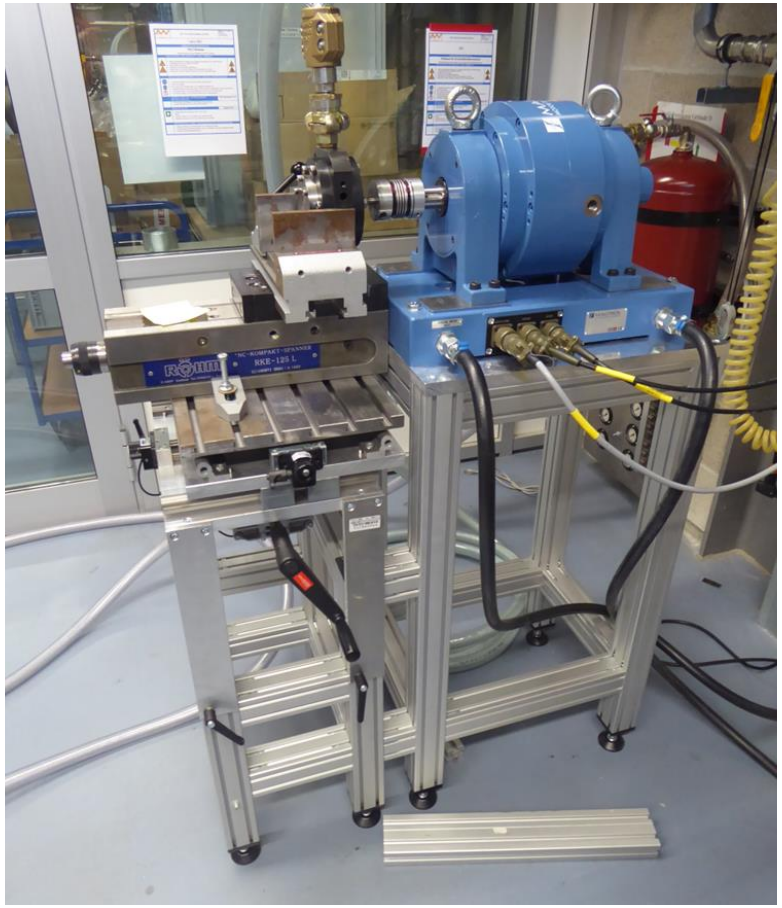
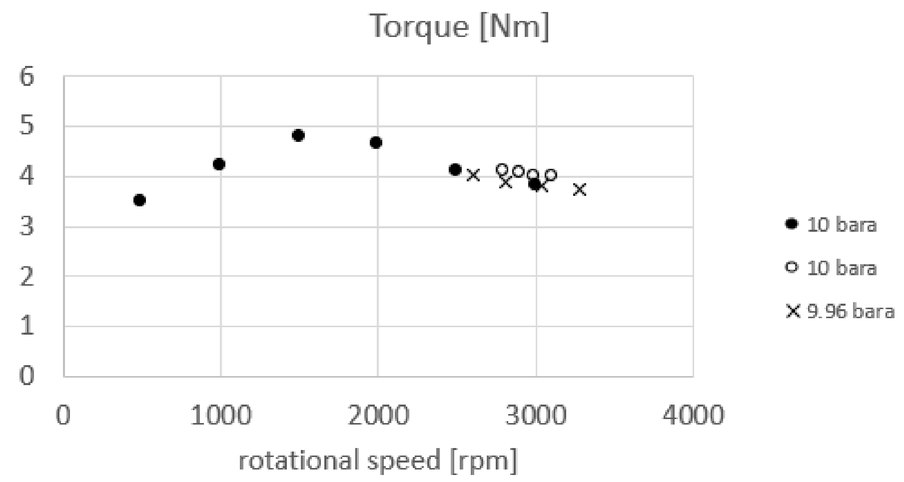
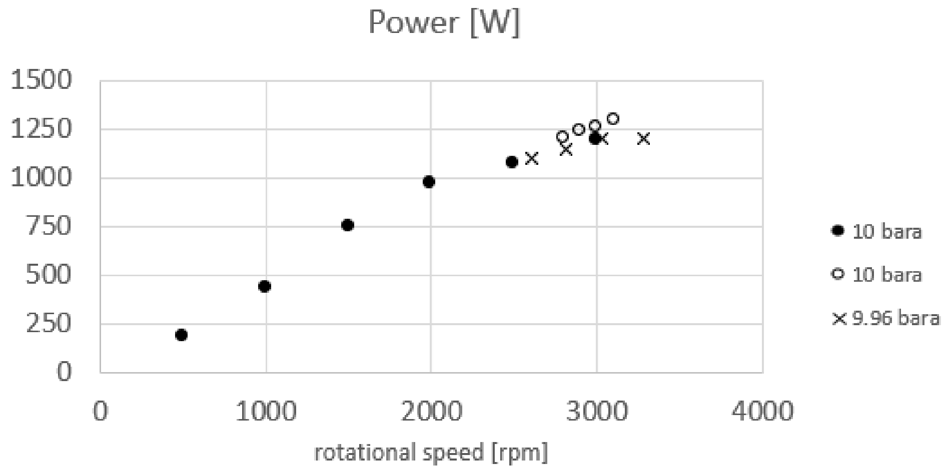
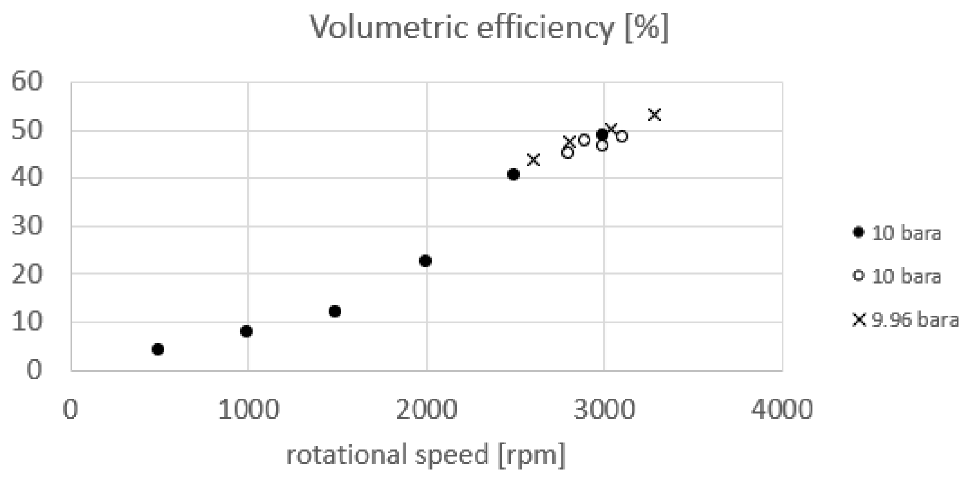


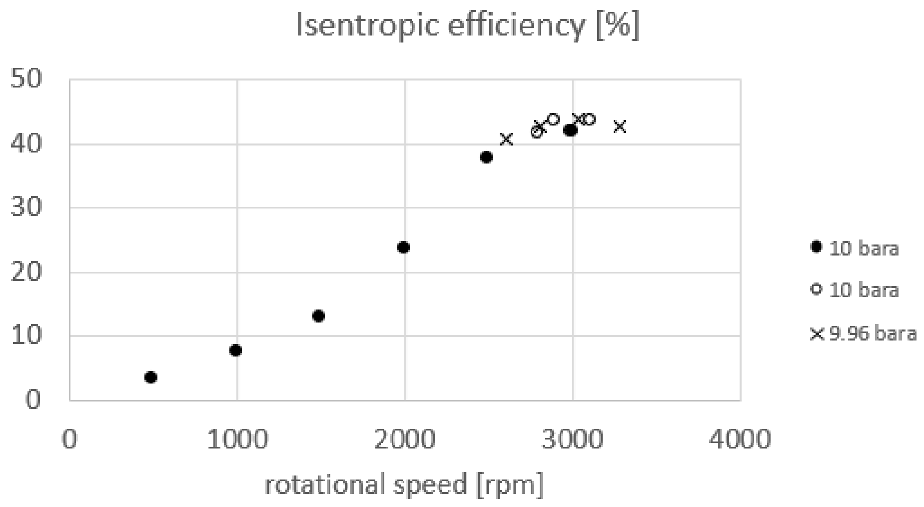
Fig. 10 Testing of air RVE

4. AIR RVE MEASUREMENT









4. AIR RVE MEASUREMENT

- Maximum achieved power output:

  1.3 kW @ 3000 rpm & 10 bar(abs)

- Maximum achieved efficiency:

  isentropic: 44 %, volumetric: 54 % (still large space for improvement)

- Minor discrepancies with the mathematical model (larger mass flow and larger power output then expected) – might indicate problems with loss of contact between vanes and stator

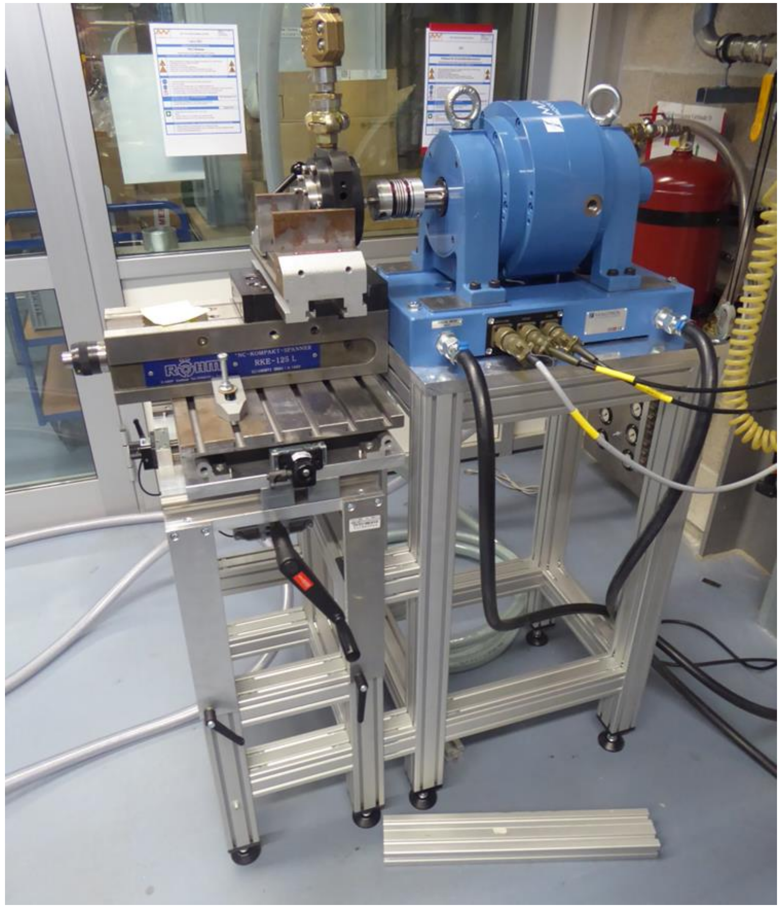


Fig. 10 Testing of air RVE

4. AIR RVE MEASUREMENT: LIFE-TIME TESTING

- Focused mainly on the wear of the vanes
- Short-term but without damage after oil-free testing
- Long-term (>> 1000h) tests will continue also after end of the project

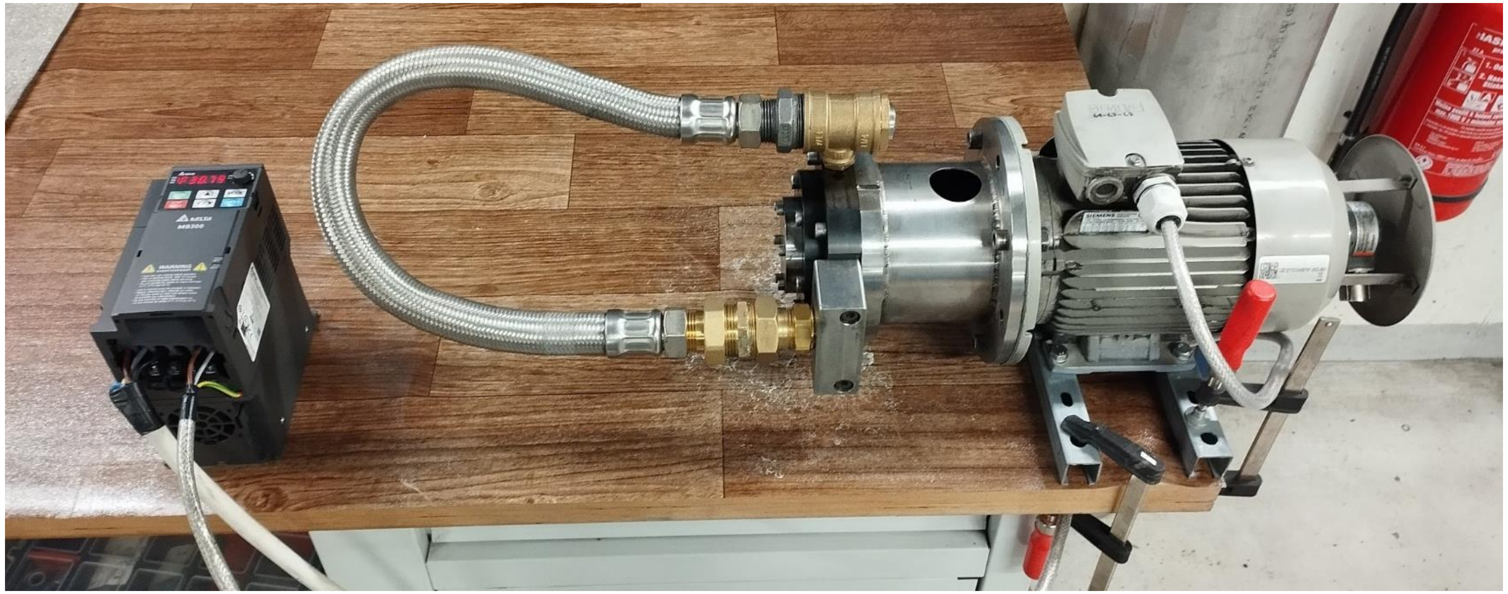


Fig. 11 Long-term lifetime tests

Fig. 12 Air RVE vanes check

5. CONCLUSION & FUTURE WORK

- Operational tests have proven the suitability of using small RVEs for low power applications where it achieves good efficiency and high performance
- Preliminary (short-term) test showed capability of oil-free operation without damage of DLC layers
- Still large possibilities of further optimization of DLC layers
- Long-term operation and lifetime tests (thousands of operation hours) are subject of future work

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