清華大學
Tsinghua University

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Unsteady Leakage Flow through Axial Clearance of an ORC Scroll Expander

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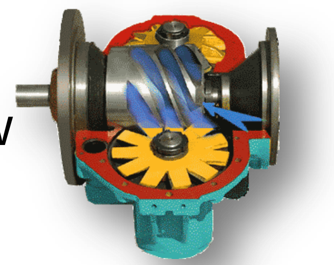
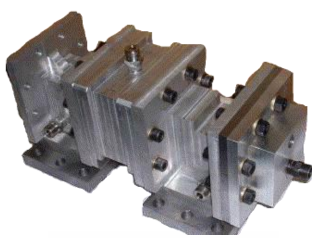
Contents

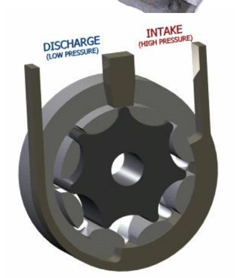
Introduction

Classification

- Volumetric type
  - Scroll
  - Screw
  - Piston
  - Rotary vane
  - Gerotor
  - Rolling rotor
- Velocity type
  - Turbine







Introduction

Scroll expander

- High efficiency
- Compact structure
- Low speed
- Low noise
- High reliability

Internal clearance leakage

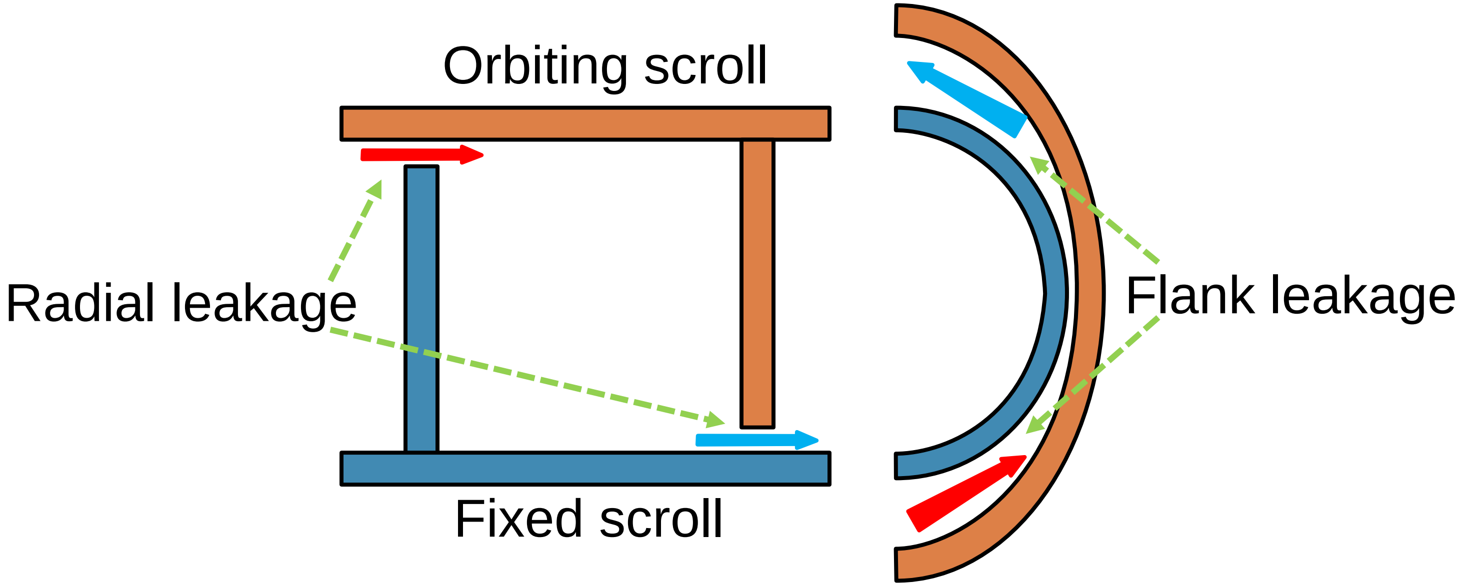
External leakage

Heat dissipation

Mechanical friction

Efficiency reduction

Introduction



- Interfering with the flows in the upstream/ downstream gas chambers
- Reduction of gas expansion capacity in gas chambers
- Increment of the energy losses in gas chambers

Introduction

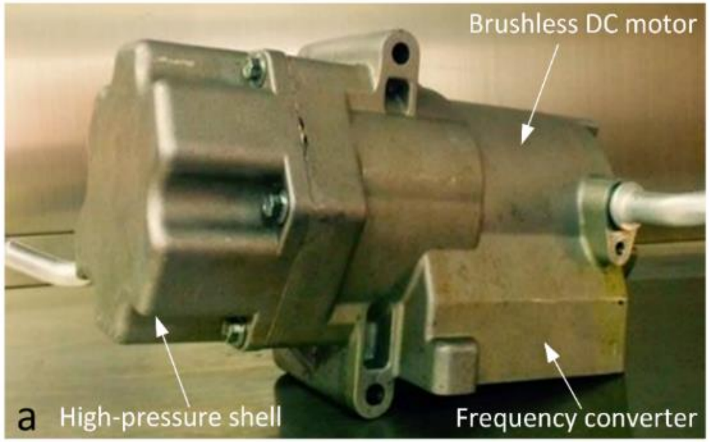
- **Isentropic compressible nozzle flow model**
- **Compressible adiabatic flow with fanno flow model**
- **Incompressible and viscous pipe flow model**
- **One-dimensional laminar flow model**
- **Incompressible, viscous and turbulent flow model**

- Unsteady behaviors of radial leakage flow
- Influences on the gas flow in working chamber

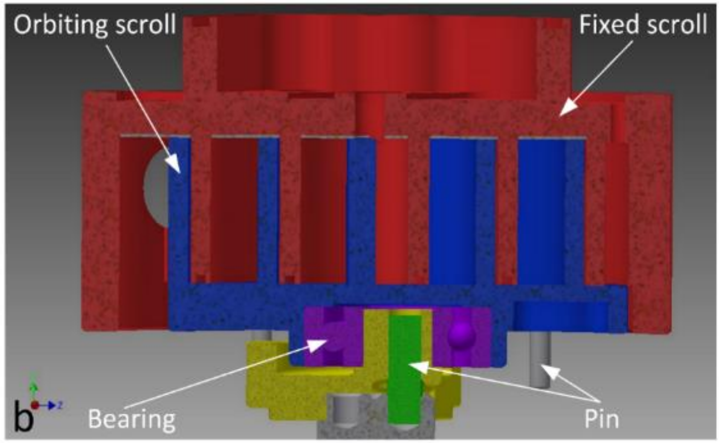
Contents

Methodology

- **Geometric model of STE**



overall view



cross-section view

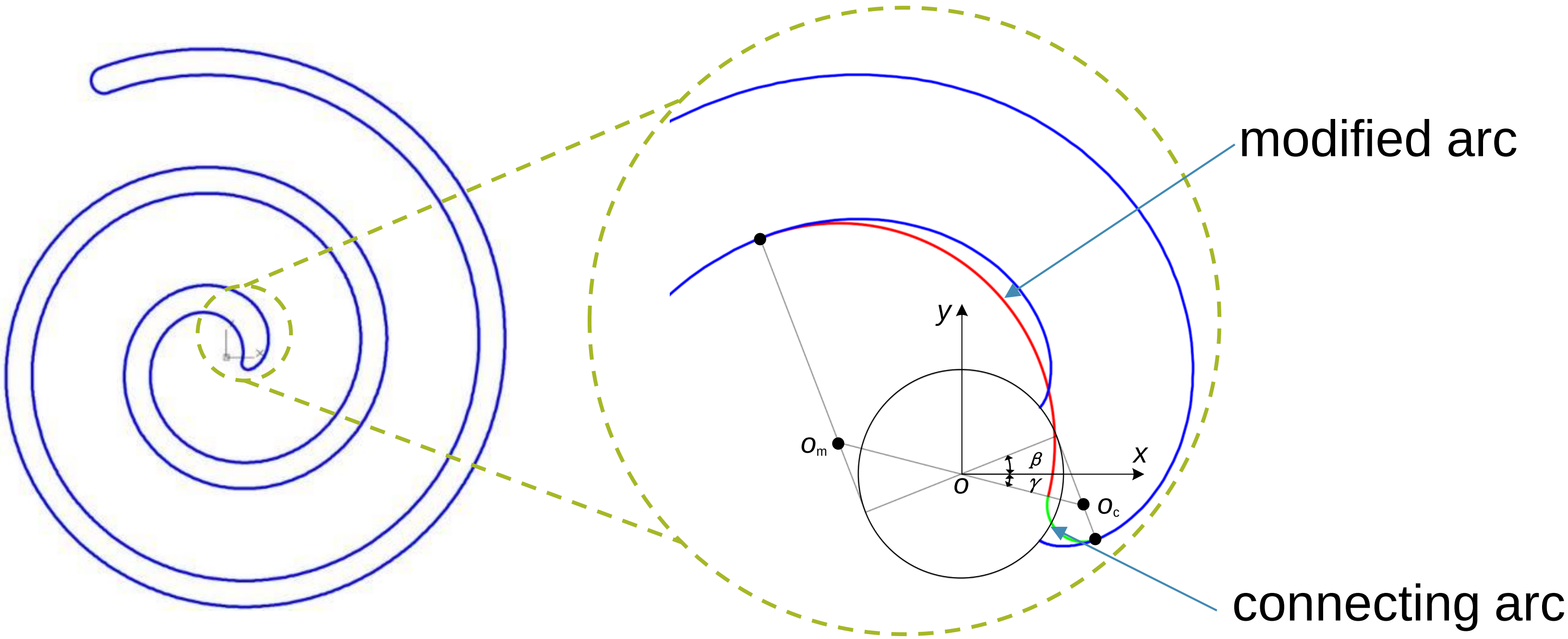
Specifications of scroll compressor

Displacement	Speed range	Motor type	Nominal Votage	Voltage range
34 ml/r	2500~8000rpm	Brushless DC	DC 330V	DC 0~400V

Methodology

Geometric model of STE

- Constant scroll wrap thickness (basic circle)
- Double arc modification of top profile



Fixed scroll

Top scroll modification

Methodology

Geometric model of STE

- Point coordinates on the basic circle involute

Inner Involute:

$$\begin{cases} x_\mathrm{i} = r_\mathrm{b}(\cos\varphi_\mathrm{i} + (\varphi_\mathrm{i} - \alpha_\mathrm{i})\sin\varphi_\mathrm{i}) \\ y_\mathrm{i} = r_\mathrm{b}(\sin\varphi_\mathrm{i} - (\varphi_\mathrm{i} - \alpha_\mathrm{i})\cos\varphi_\mathrm{i}) \end{cases}$$

Outer Involute:

$$\begin{cases} x_\mathrm{o} = r_\mathrm{b}(\cos\varphi_\mathrm{o} + (\varphi_\mathrm{o} - \alpha_\mathrm{o})\sin\varphi_\mathrm{o}) \\ y_\mathrm{o} = r_\mathrm{b}(\sin\varphi_\mathrm{o} - (\varphi_\mathrm{o} - \alpha_\mathrm{o})\cos\varphi_\mathrm{o}) \end{cases}$$

Design parameters: $(r_\mathrm{b}, \alpha_\mathrm{i}, \alpha_\mathrm{o}, \varphi_\mathrm{e})$ (β, γ)

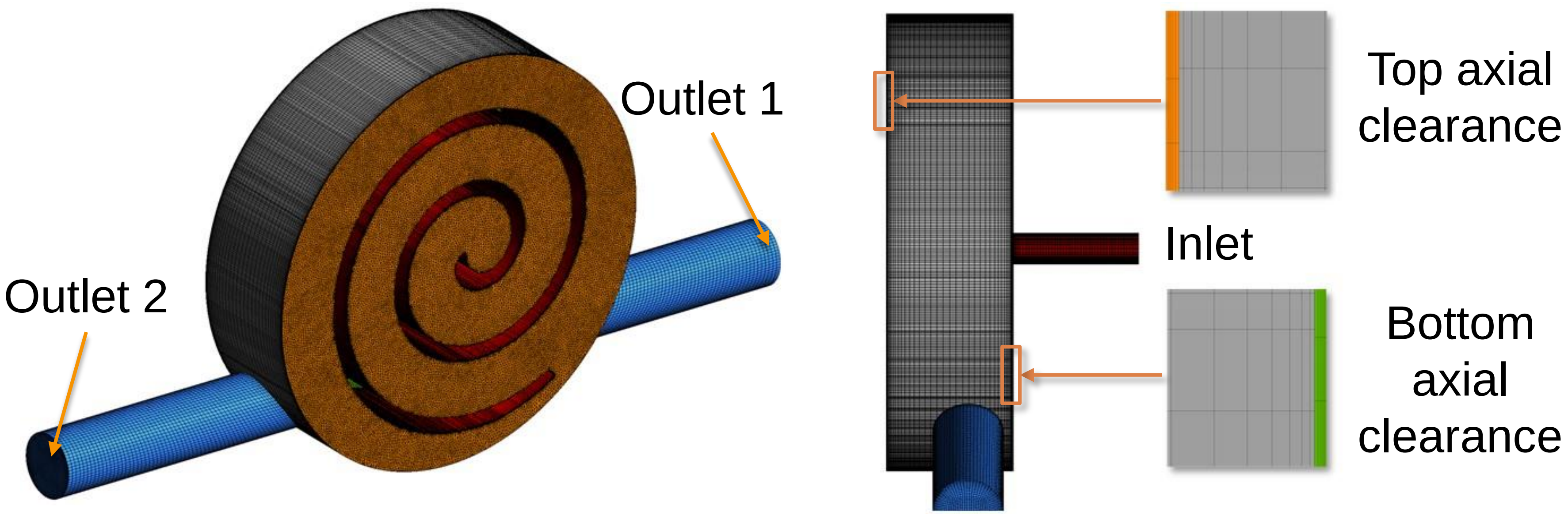
Methodology

- Geometric model of STE

Parameters	r_b	R_{or}	t	P	α	β	γ
Unit	(mm)	(mm)	(mm)	(mm)	(rad)	(rad)	(rad)
Value	2.39	4.2	3.3	15	0.69	0.373	0.247
Parameters	$\varphi_{s, in}$	$\varphi_{s, ou}$	φ_e	H	D	d_{suc}	d_{dis}
Unit	(rad)	(rad)	(rad)	(mm)	(mm)	(mm)	(mm)
Value	3.515	0.373	16.06	24	87.4	6	13.5

Methodology

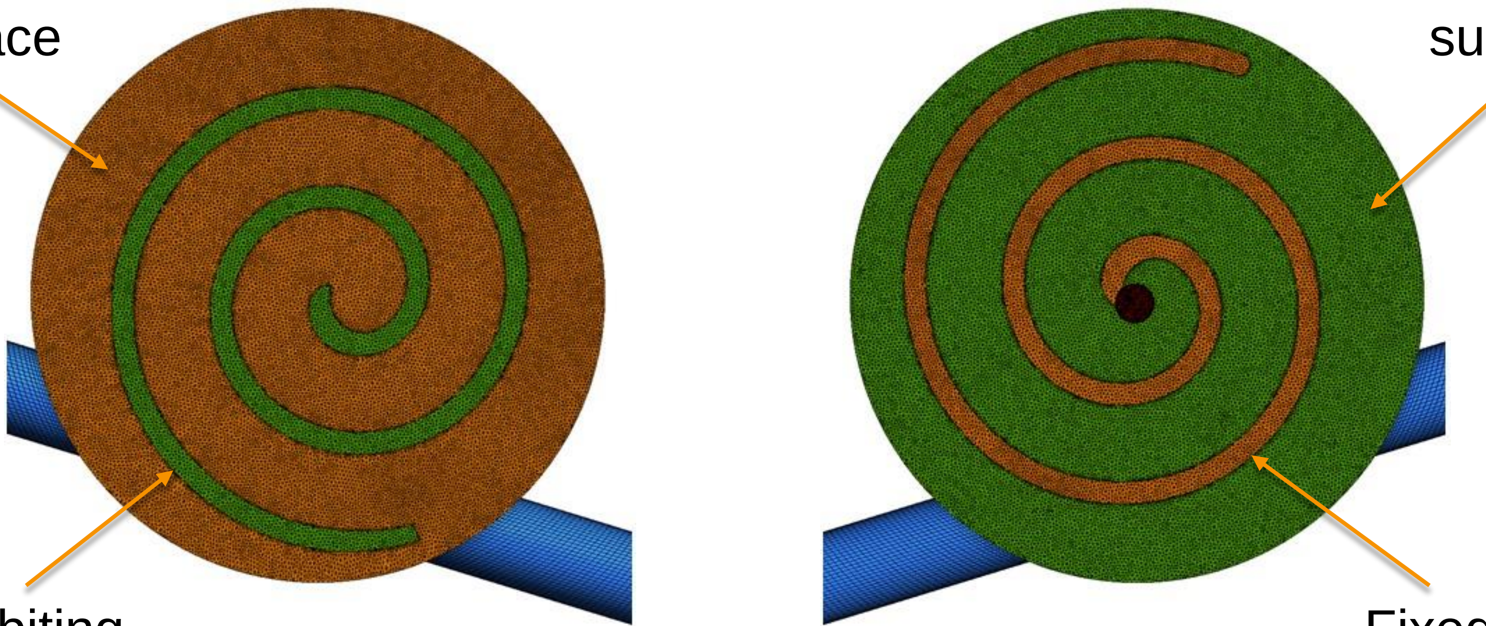
▫ Numerical model and solution method



Mesh generation of fluid domain

Methodology

- **Numerical model and solution method**



Mesh generation of fluid domain

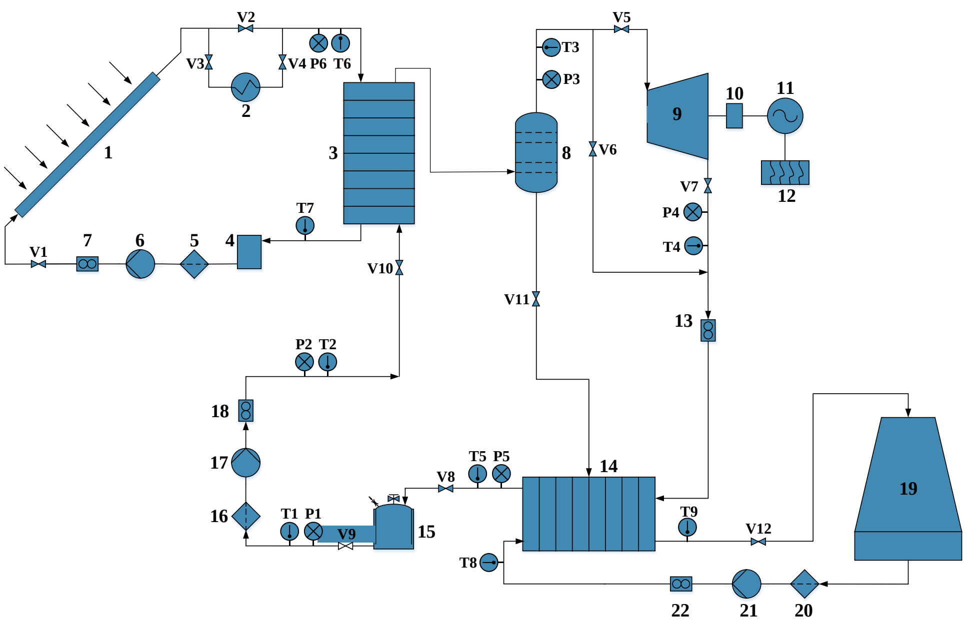
Methodology

- **Numerical model and solution method**
  - RNG k-e turbulence model
  - Standard wall function
  - First order backward difference scheme
  - Second order upwind scheme
  - PRESTO (Pressure staggered option) scheme
  - Second order central difference scheme
  - PISO algorithm

Methodology

▫ Numerical model and solution method

1kW solar-ORC system



Operating condition of STE

	Unit	Value
Inlet pressure	MPa	1.1
Inlet temperature	K	378
Outlet pressure	MPa	0.3
Rotating speed	r/min	3200
Working fluid	-	r245fa

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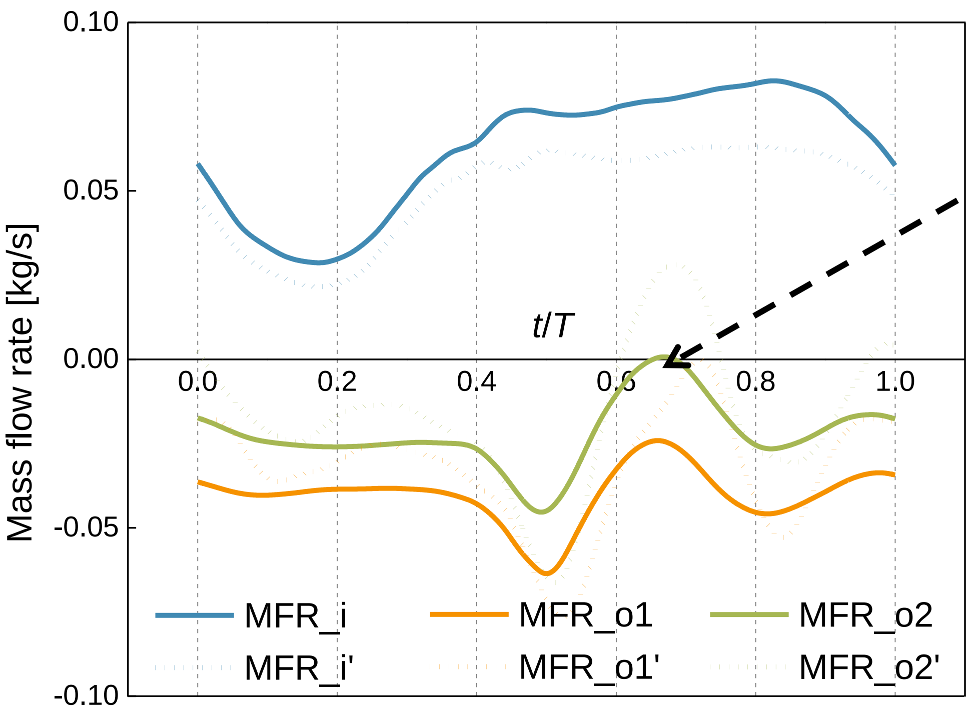
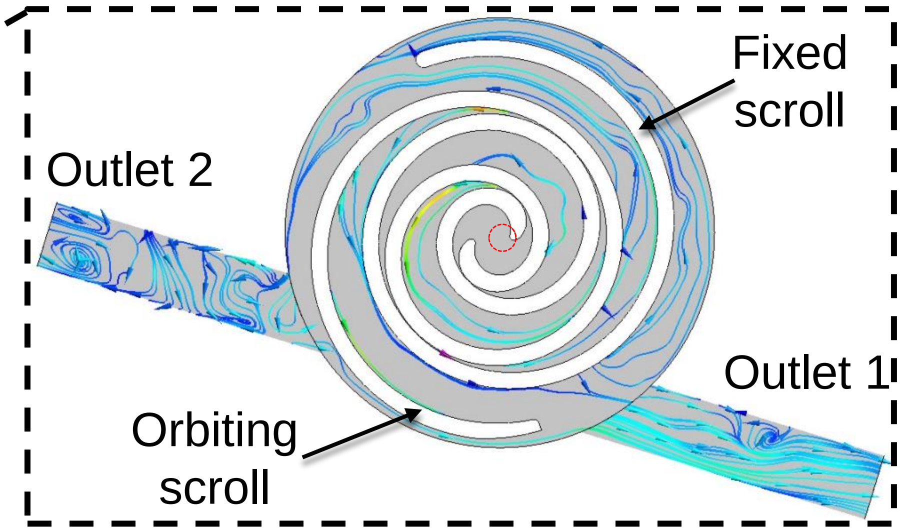
Results and discussion

Expander transient performance





- Higher mass flow rate
- Lower discharge flow fluctuation
- Different discharge flow capacity

- Reverse discharge flow

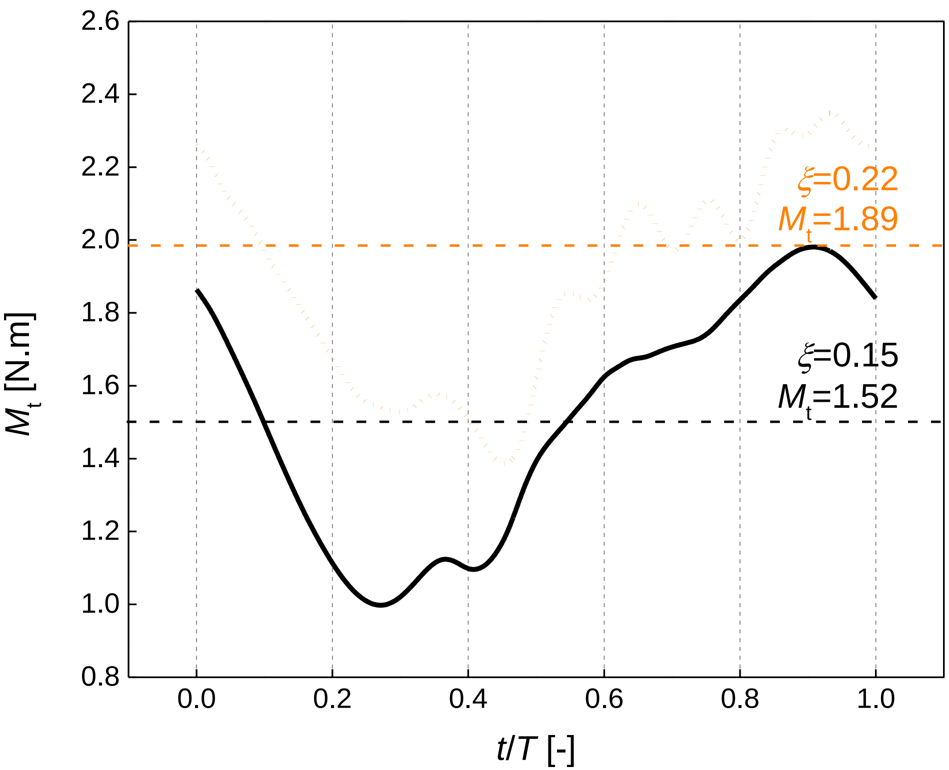
Results and discussion

Expander transient performance

$$F_t = \sum_{i=1}^{n} \left(F_{y,i} \cos\left(\frac{\pi N}{30} t\right) - F_{x,i} \sin\left(\frac{\pi N}{30} t\right) \right)$$

$$M_t = R_{or} \sum_{i=1}^{n} F_{t,i}$$

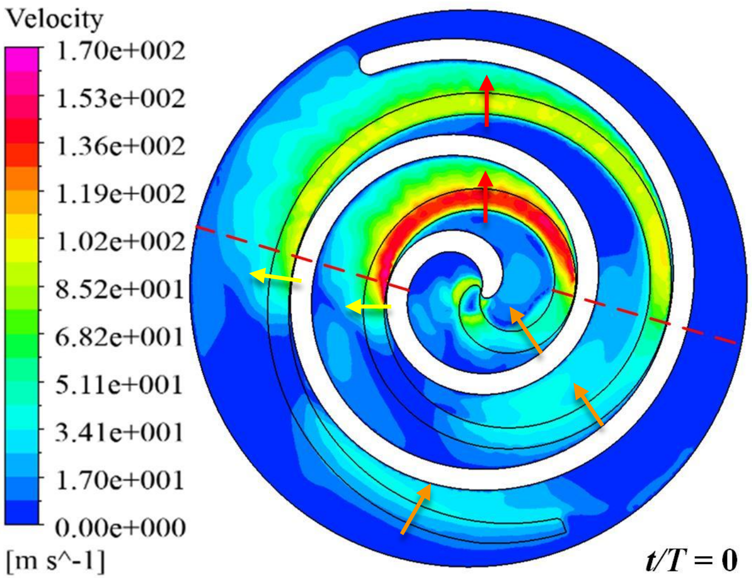
$$\xi = \sqrt{\frac{1}{N} \sum_{j=1}^{N} (\phi_j - \bar{\phi})^2} \Big/ \bar{\phi}$$



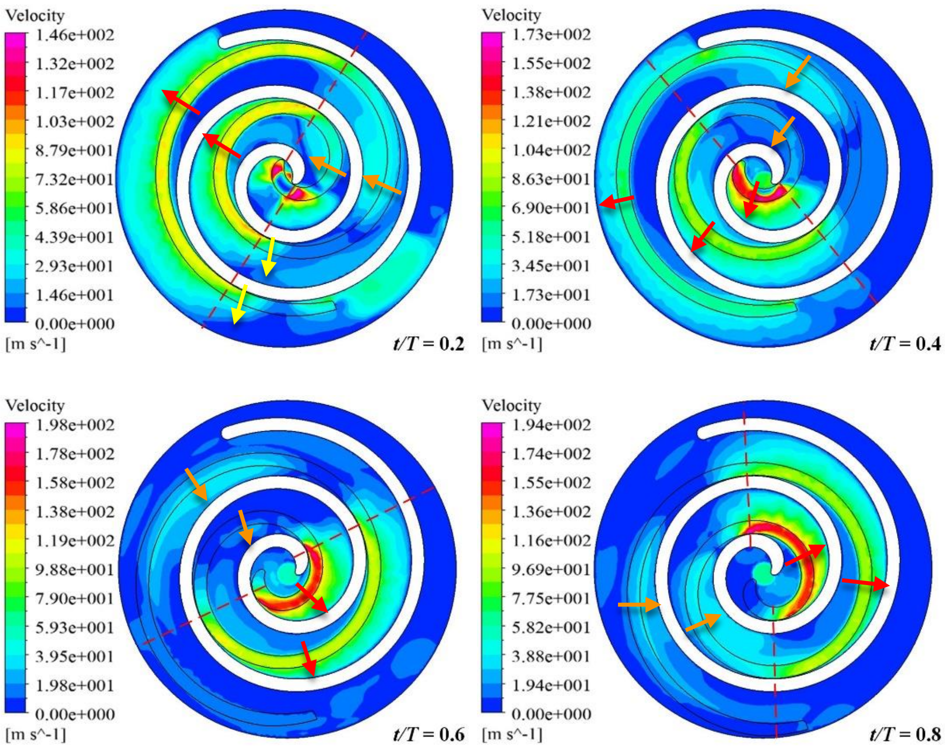
- Smaller gas driving moment
- Smaller fluctuating coefficient
- Effects of discharge flow

Results and discussion

Velocity distribution in axial clearances



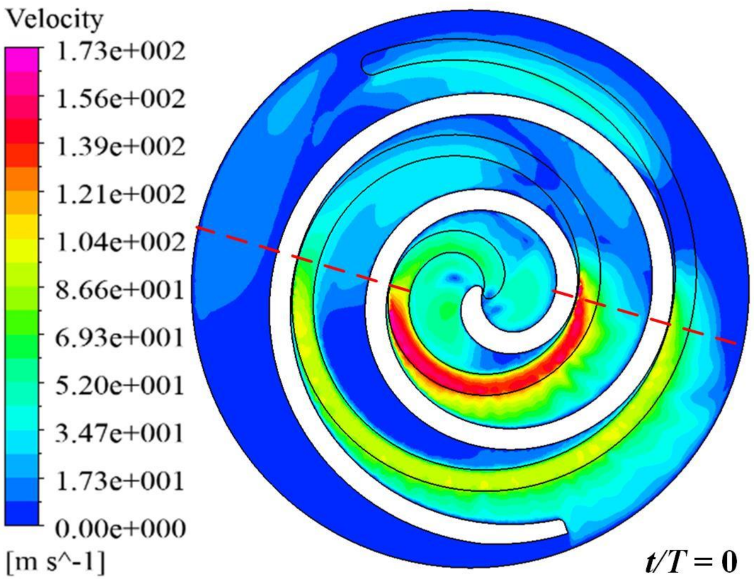
Bottom axial clearance



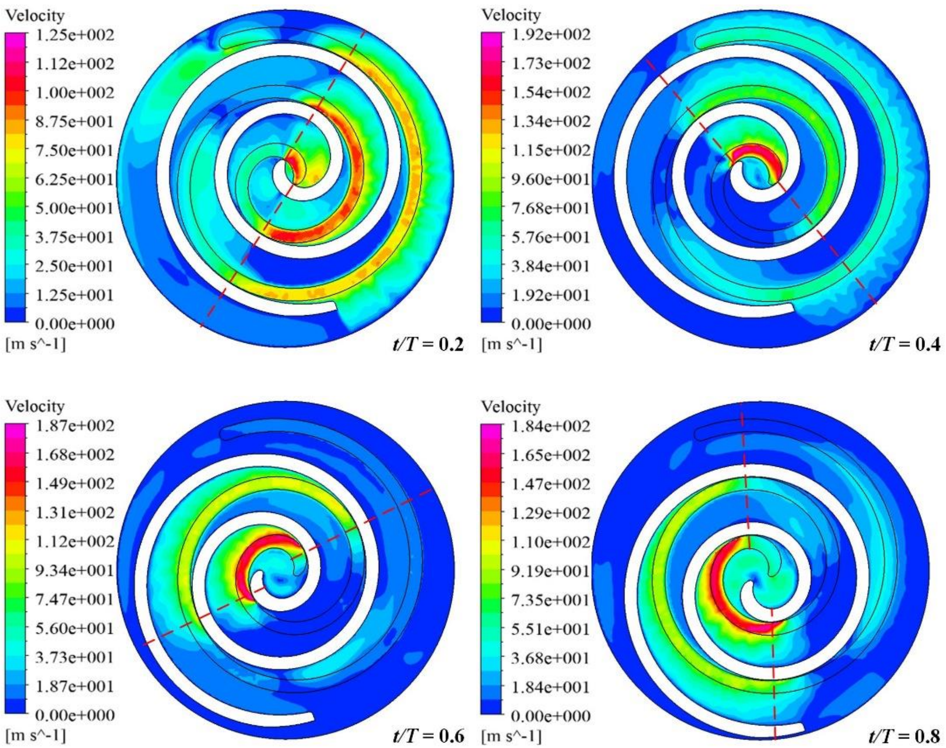
- Radial leakage between asymmetrical chambers
- Radial leakage between symmetrical chambers

Results and discussion

▫ Velocity distribution in axial clearances



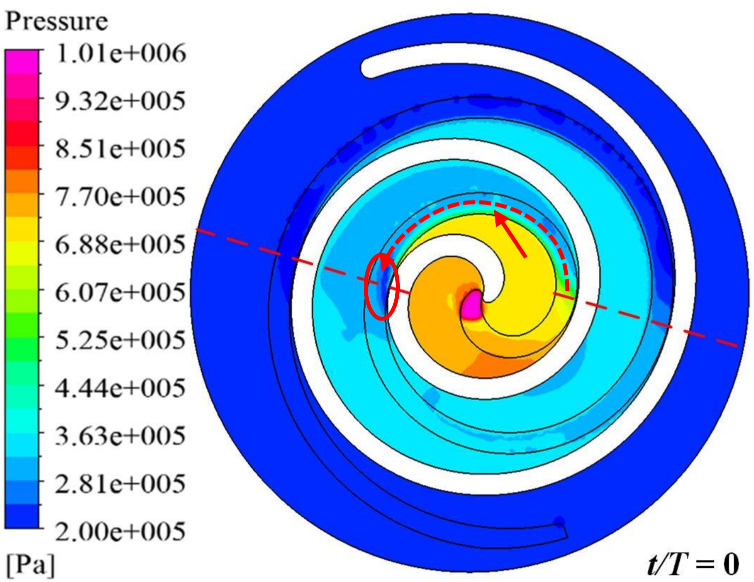
Top axial clearance



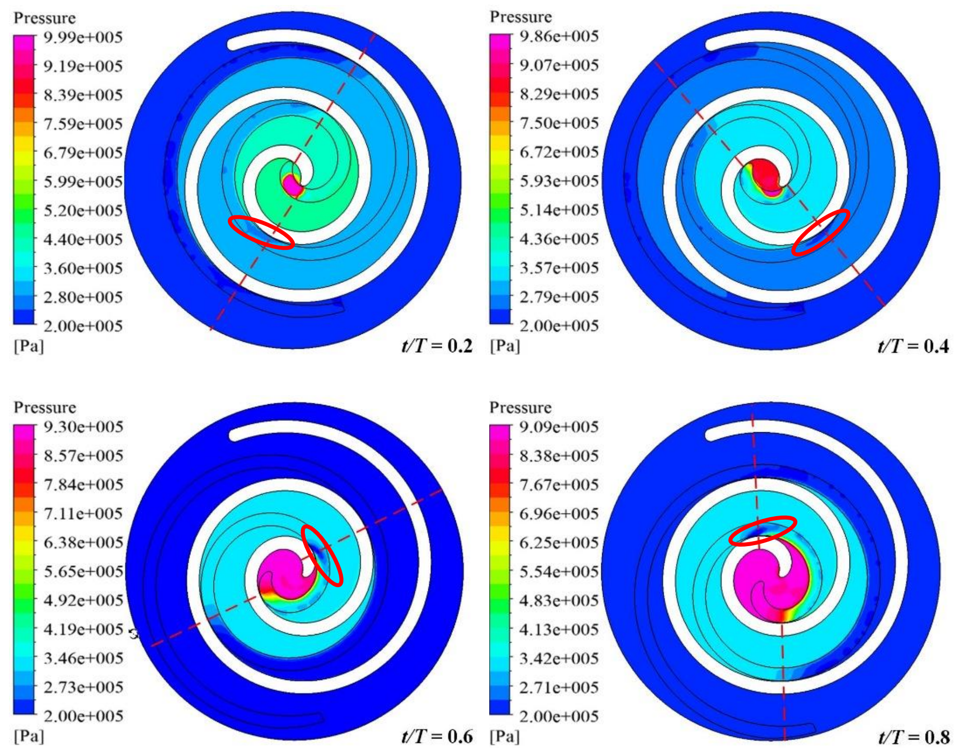
- Asymmetric velocity distribution between two axial clearances

Results and discussion

Pressure distribution in axial clearances



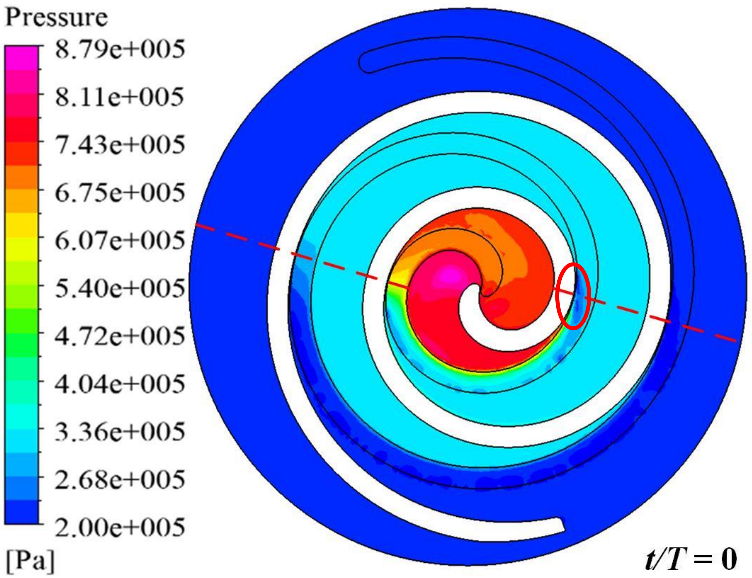
Bottom axial clearance



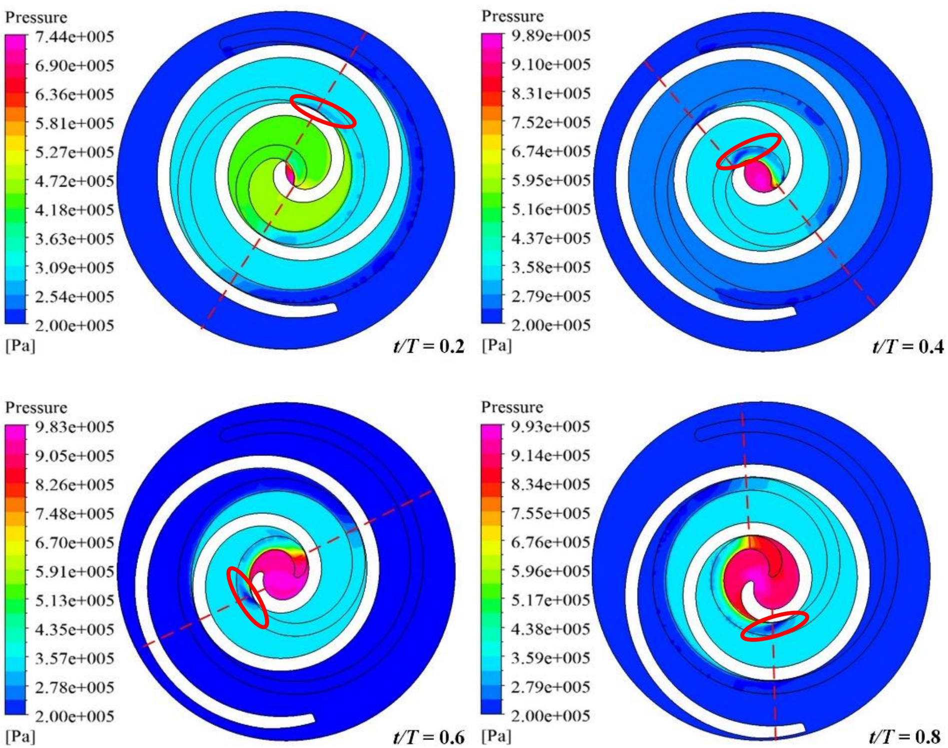
- Pressure gradient at clearance inlet between asymmetric chambers
- Non-uniform pressure in axial clearance along the scroll involute
- Pressure distortion occurs in the downstream of axial clearance

Results and discussion

- **Pressure distribution in axial clearances**

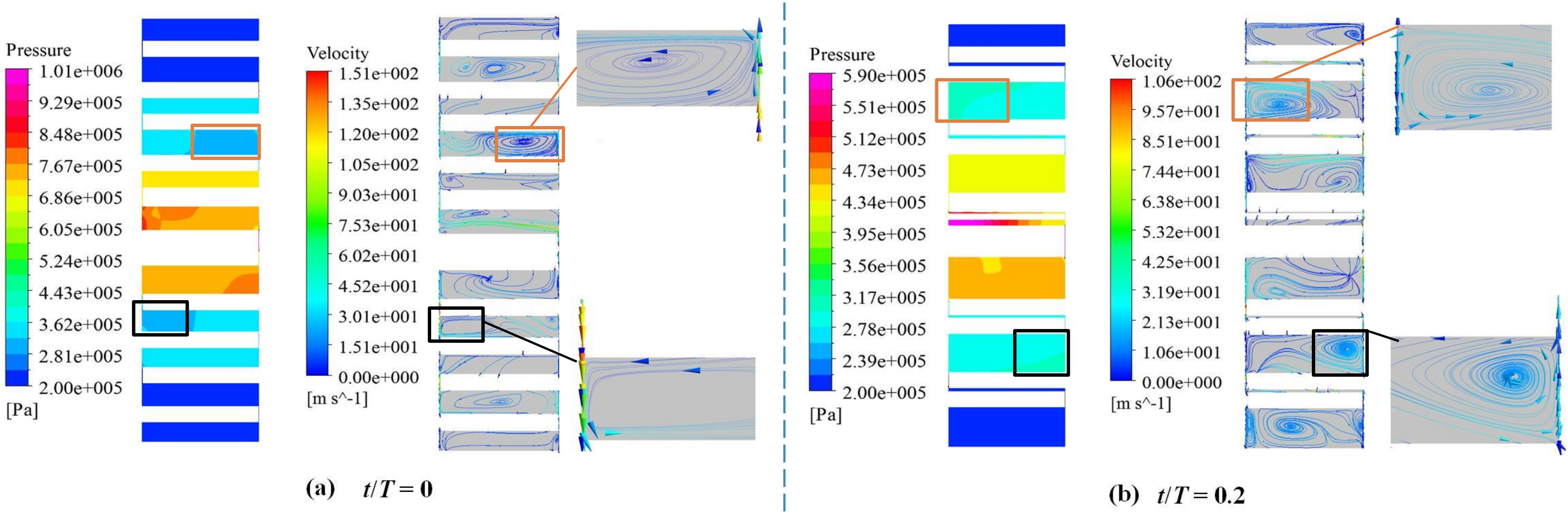


Top axial clearance



Results and discussion

Effects of radial leakage in working chambers

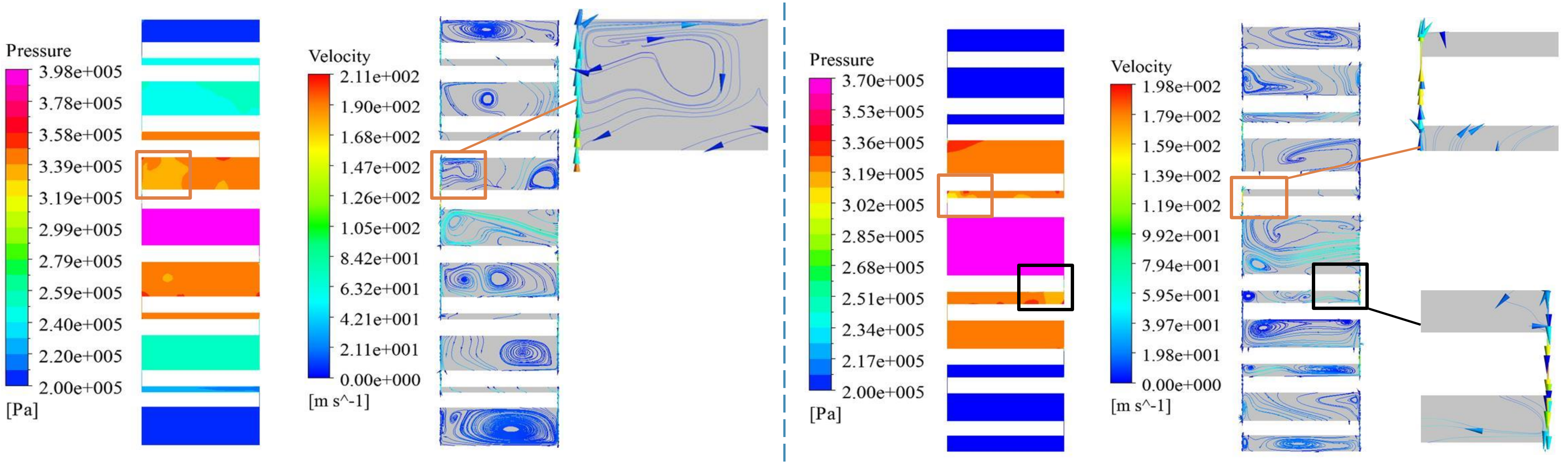


(a) $t/T = 0$ (b) $t/T = 0.2$

- Low pressure region in symmetric working chambers
- Vortices: Leakage flow, fluid viscous force , wall constraint

Results and discussion

Effects of radial leakage in working chambers



(c) $t/T = 0.4$ (d) $t/T = 0.6$

- Stronger vortex flow nearby top axial clearance
- Pressure distortion in the expansion chambers at the scroll tip and root

Contents

Conclusions

- Radial leakage flows occur at not only the axial clearances of the scroll segments between asymmetrical chambers but also those between symmetrical chambers.
- Radial leakage flows through the top and bottom axial clearances are approximately symmetrical about the meshing line.
- Non-uniform pressure distribution in the axial clearance passage exists along the scroll involute direction.
- Large pressure distortion occurs in the downstream of the axial clearance between asymmetric working chambers.
- Radial leakage flow leads to secondary vortex flow and non-uniform pressure distribution in working chambers.

Thanks for your attention!

Questions are welcome!

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