Université de Liège

LABORATOIRE DE THERMODYNAMIQUE UNIVERSITE DE LIEGE

Massachusetts Institute of Technology

STG International

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Non-constant wall thickness scroll expander investigation for a micro solar ORC power plant

by

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PRESENTATION STRUCTURE

1) Context and Issues
2) Optimal scroll geometries selection
3) CAD modeling of a single stage prototype
4) Prototype fabrication and assembly
5) Conclusion and perspectives

PART 1

CONTEXT AND ISSUES

1. Context and Issues

Environmental concerns

Electricity access in developing countries

Favorable insolation conditions

MicroCSP

Photovoltaic

MicroCSP = Micro “Concentrated Solar Power” plant |||| ORC = Organic Rankine Cycle

1. Context and Issues

Environmental concerns

Electricity access in developing countries

Favorable insolation conditions

MicroCSP

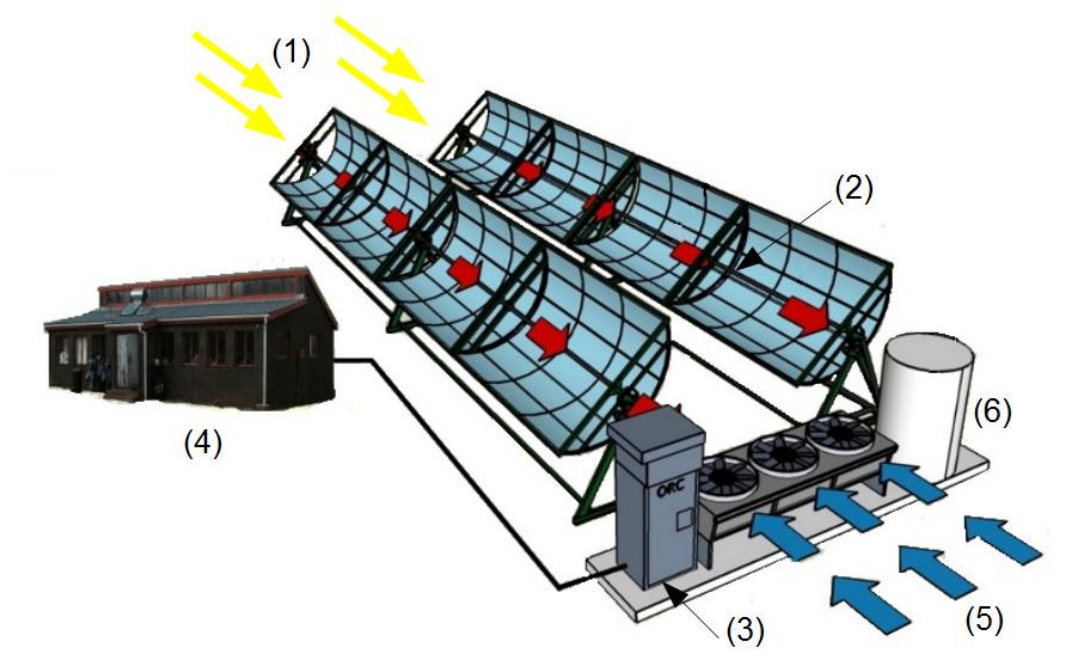
Photovoltaic

- Thermal storage ⇔ Batteries
- Cogeneration available
- Hybridization with a back up generator

MicroCSP = Micro “Concentrated Solar Power” plant |||| ORC = Organic Rankine Cycle

1. Context and Issues

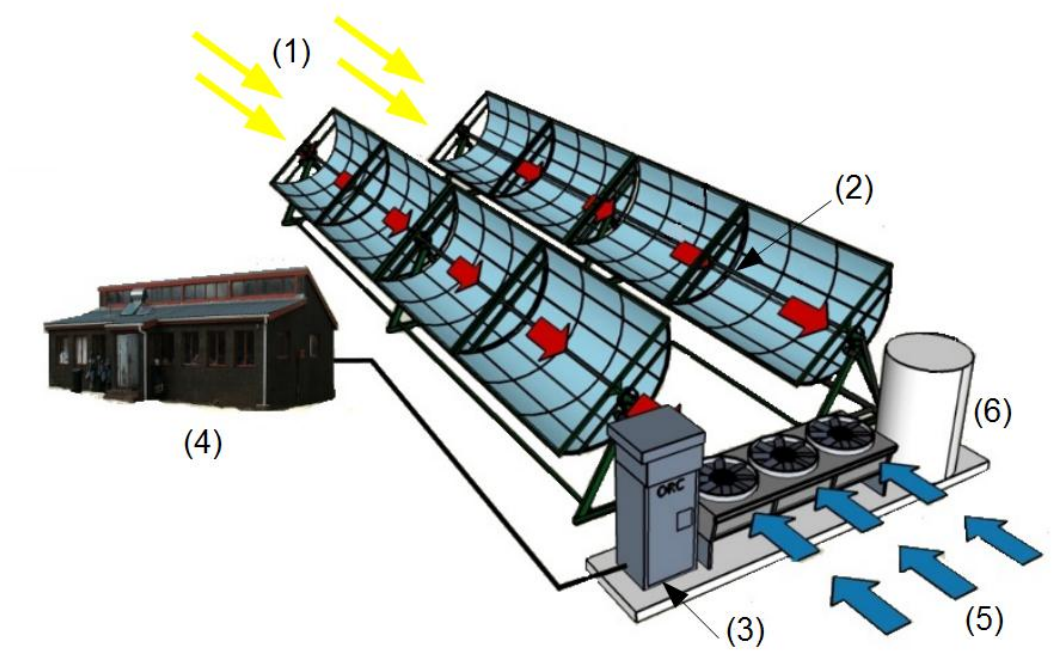
MicroCSP description:

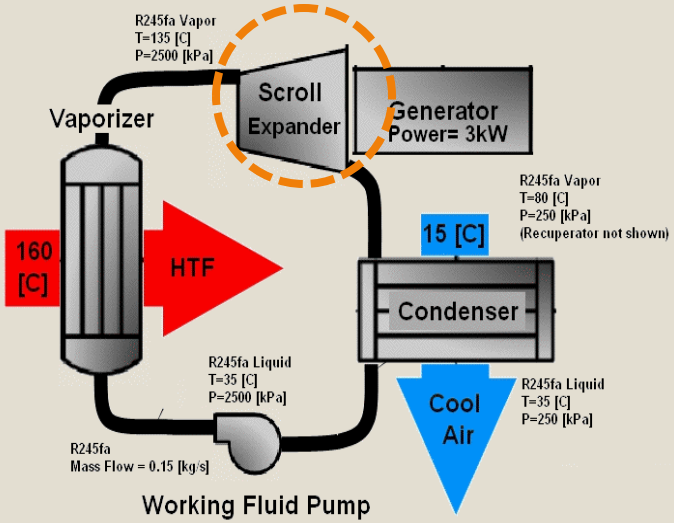


1) Sun rays
2) Parabolic trough collectors
3) ORC unit
4) Off-grid electric load
5) Ambient air
6) Thermal storage

1. Context and Issues

MicroCSP description:





Operating conditions (T_{ev}/T_{cond})

↓

Low Carnot efficiency

↓

Improve expansion device

MicroCSP = micro 'Solar Power Power' plant

1. Context and Issues

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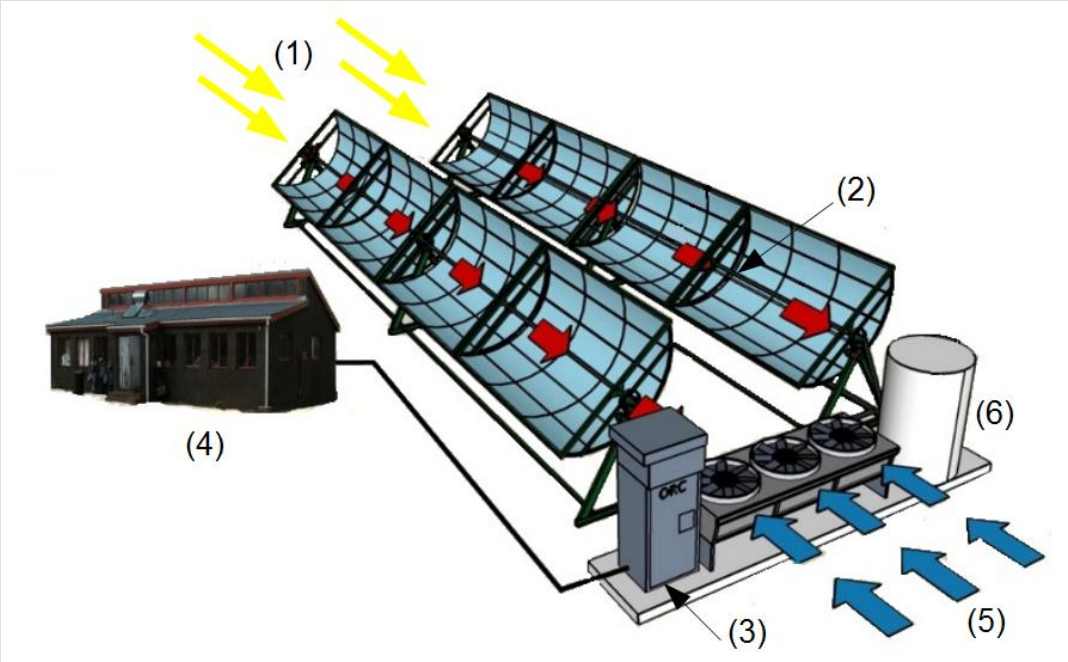

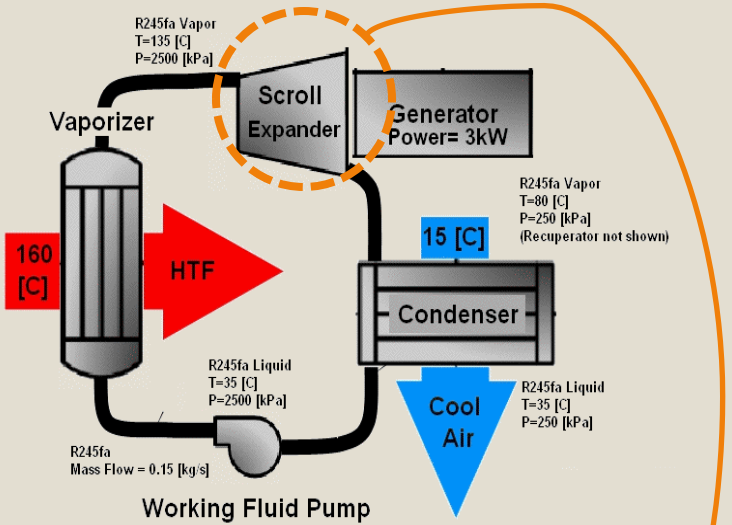

MicroCSP = micro 'Solar Power Power' plant

1. Context and Issues

Motivations for a new design of scroll expander

- Optimized internal volumetric ratios
- Two-stage/single-shaft architecture
  - Single signal frequency f and output voltage V
  - Half of the power electronic required ➔cheaper and more simple
- Variable wall thickness profile
  - More compact expansion device
  - Heat and mechanical losses reduced

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$CF = \frac{r_v}{D}$ ➔ prop. to η_{is}

PART 2

OPTIMAL SCROLL GEOMETRIES SELECTION

2. Optimal scroll geometries selection

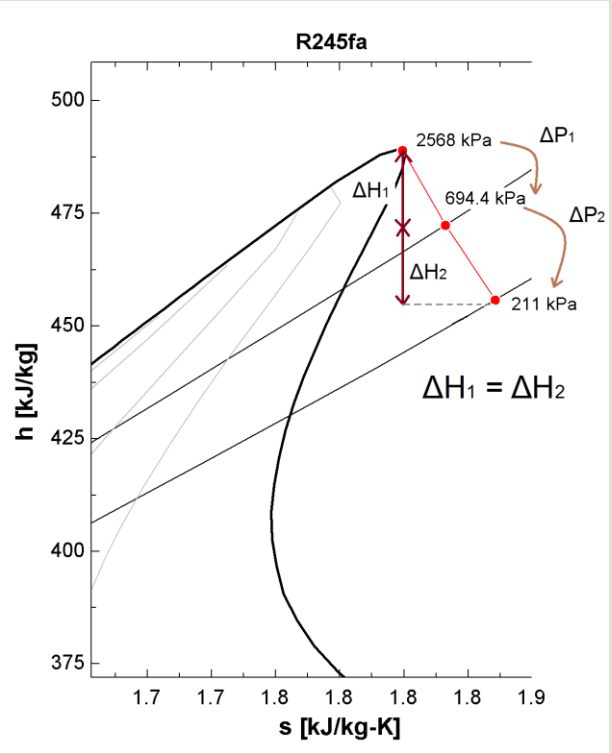
- Operating requirements given by a steady-state model (EES)
  - 135°C ➔ 35°C
  - 5kW
  - R245fa
  - 3000 rpm
  - $\dot{W}_{1st} = \dot{W}_{2nd}$

$r_{v,1st} = 4.9$

$r_{v,2nd} = 3.36$

$\dot{m}$ =0.15 kg/s

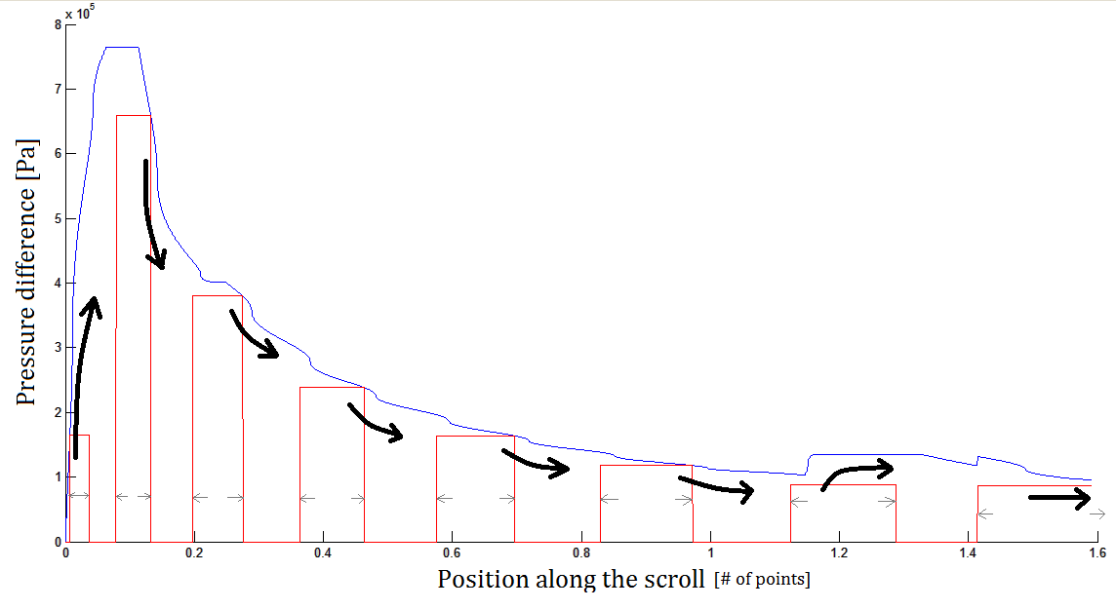
V_{in}

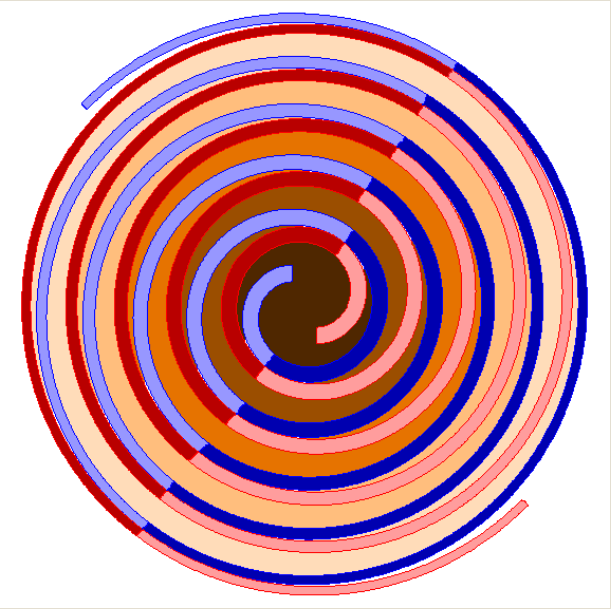


2. Optimal scroll geometries selection

- Minimum wall thickness requirement

  ↳ Cantilever beam theory : $e_{min} = \sqrt[3]{\frac{3 \,.\, \Delta P \,.\, h^5}{2\, E\, \delta_{max}}}$





2. Optimal scroll geometries selection

26.000 scrolls database → r_v criteria, CF ranking → 26 candidates → Deterministic modeling → 2 geometries selected

Danfoss frame

1 geometry ⇔ 8 parameters

$$s_x = c_1 + c_2 \varphi + c_3 \varphi^2 + c_4 \varphi^3 + c_5 \varphi^4$$

R, d and N

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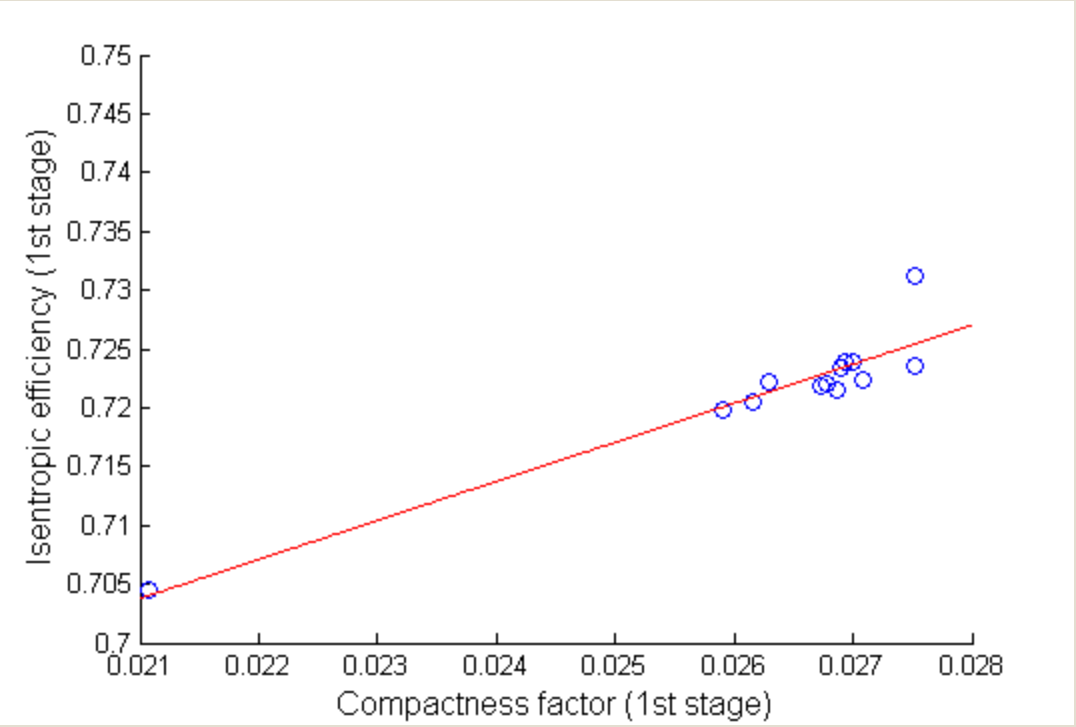

$$CF = \frac{r_v}{D}$$

prop. to η_{is}

2. Optimal scroll geometries selection

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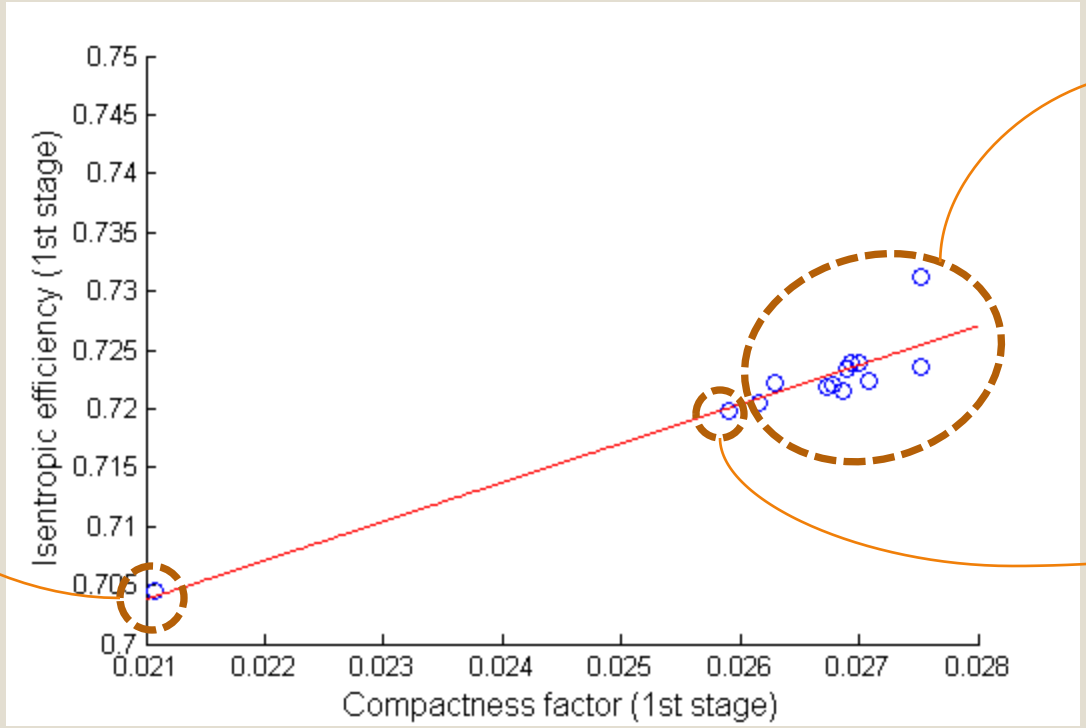
Increasing wall thickness

Decreasing wall thickness

Constant wall thickness



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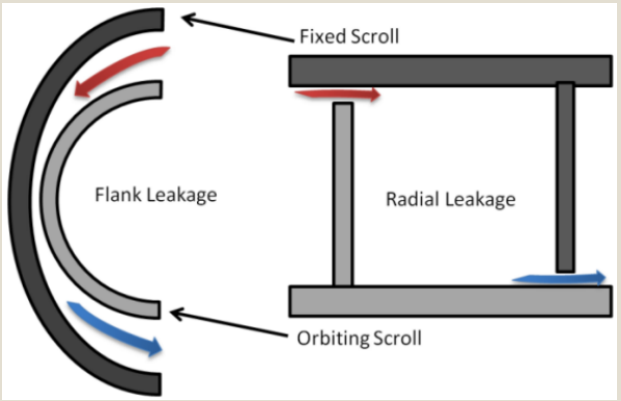
Deterministic model of a scroll expander taking into account

- Radial and flank leakages
- Intake and exhaust throttling losses
- Friction losses between the scrolls
- Mechanical losses into the bearings

→ η_{is} , $\dot{W}$, FF

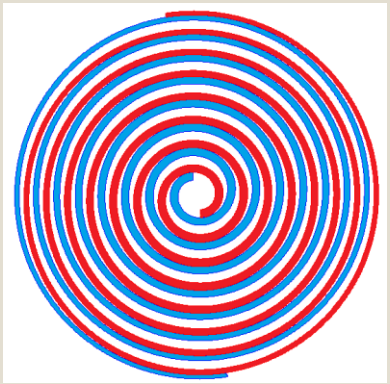


2. Optimal scroll geometries selection

26.000 scrolls database → (r_v criteria, CF ranking) → 26 candidates → (Deterministic modeling) → 2 geometries selected

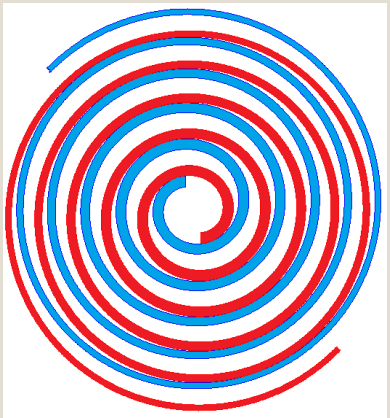
1st stage:

- $\eta_{1st,is}$ = 73.12%
- highest CF among candidates
- $\dot{W}$ = 3.03 kW



2nd stage:

- $\eta_{2nd,is}$ = 66.14 %
- highest CF among candidates
- $\dot{W}$ = 2.5 kW



Full expansion: $\eta_{is,tot}$ = 68.6 %

2. Optimal scroll geometries selection

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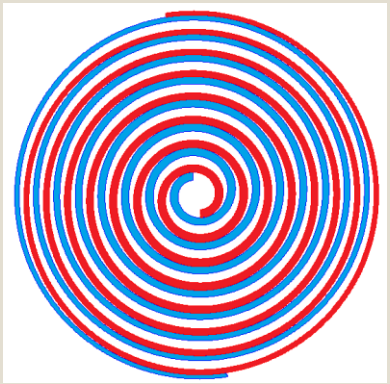

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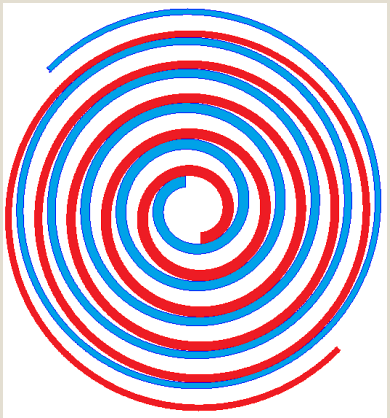

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2. Optimal scroll geometries selection

- Losses study

Losses modeled	First stage		Second stage	
----	η (%)	Δη (%)	η (%)	Δη (%)
Inlet/Outlet Throttling losses	97.19	-	88.7	-
Same as the previous + Mechanical losses	82.77	14.43	68.75	19.95
Same as the previous + Flank leakages	77.26	5.51	68.02	0.73
Same as the previous + Radial leakages	73.67	3.59	66.68	1.34
Same as the previous + Heat losses	73.12	0.55	66.14	0.54

2. Optimal scroll geometries selection

- Losses study

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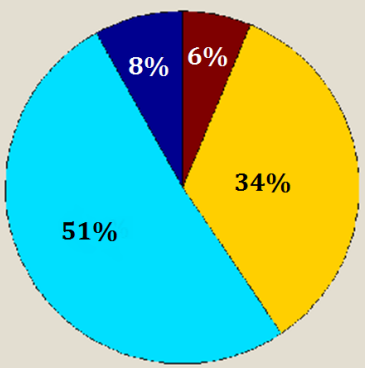
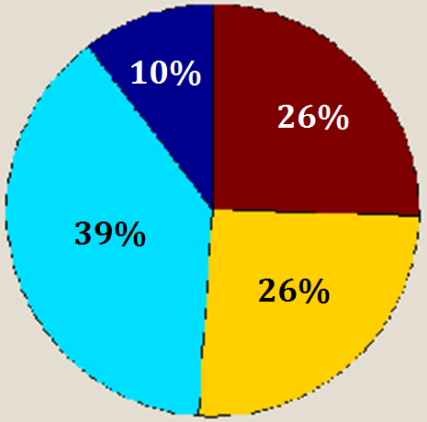
Main source : mechanical losses

2. Optimal scroll geometries selection

- Losses study : mechanical source analysis





Losses source	First stage	Second stage
Thrust bearing	42.1 W	74.06 W
Journal bearing (top)	269.8 W	276.3 W
Journal bearing (low)	179.9 W	184.2 W
Scroll friction	33.07 W	181.6 W
TOTAL	**≈530 W**	**≈ 720 W**

2. Optimal scroll geometries selection

Performance enhancement?

Design	A	B	C
Wall thickness profile	Constant	Constant	Decreasing
Volumetric ratio	2,8 (both stages)	Optimized	Optimized
$\dot{W}_{tot}$	5.04 kW	5.45 kW	5.5 kW
$\eta_{is,tot}$	62.4 %	67.43 %	68.6 %

$\Delta \eta_{is,tot} = 5.03\%$

$\Delta \eta_{is,tot} = 1.17\ \%$

$\Delta \eta_{is,tot} = +\ 6.2\%$

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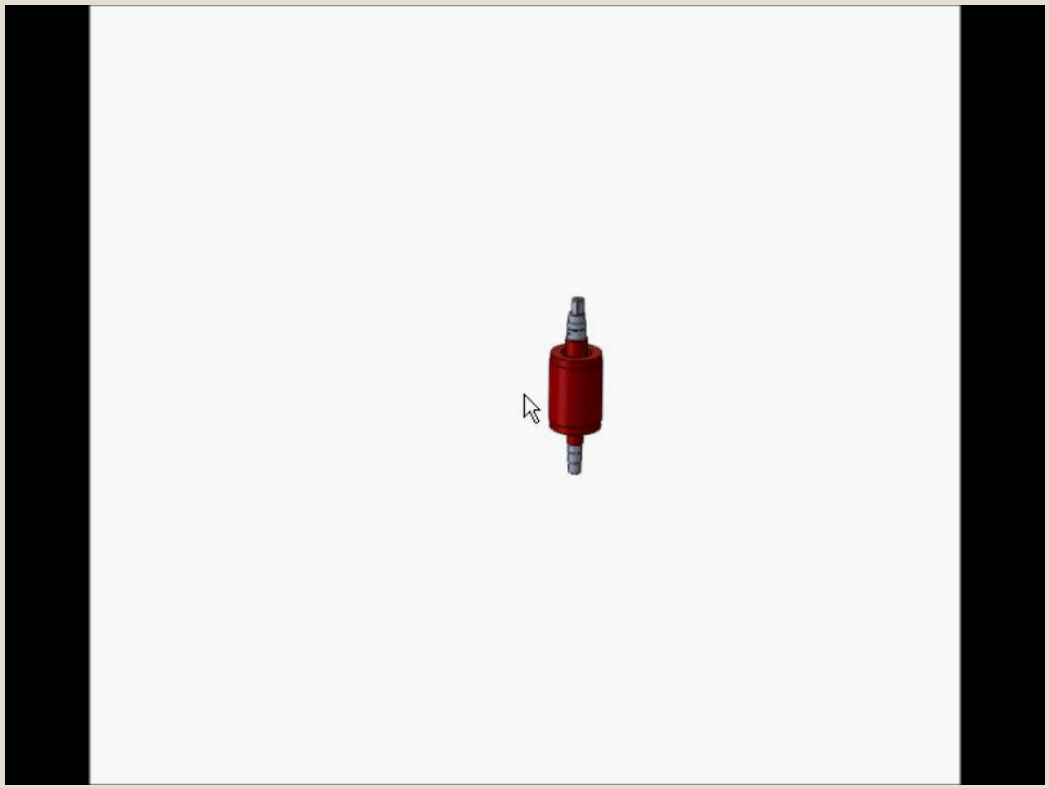
PART 3

CAD MODELING OF A SINGLE-STAGE PROTOTYPE

CAD = ‘Computer-Aided Design’

3. CAD modeling of a single-stage prototype

- CAD modeling
- SolidWorks 2012
- Architecture derived from Copeland compressors (ZR series)
- Expander: 30 assembled pieces



CAD = ‘Computer-Aided Design’

3. CAD modeling of a single-stage prototype

- Mechanical viability checked by a 60% scale 3D-printed model (FDM printer)

- Oil delivery circuit/BPC control system

- CAM with HSMXpress

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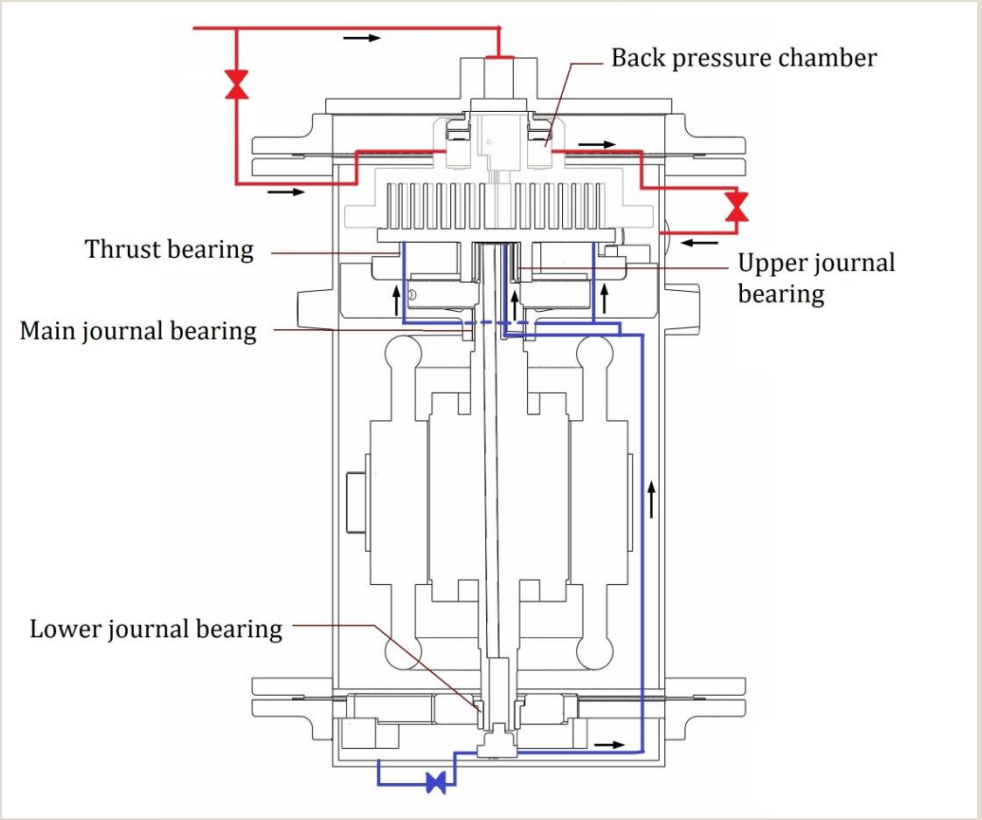

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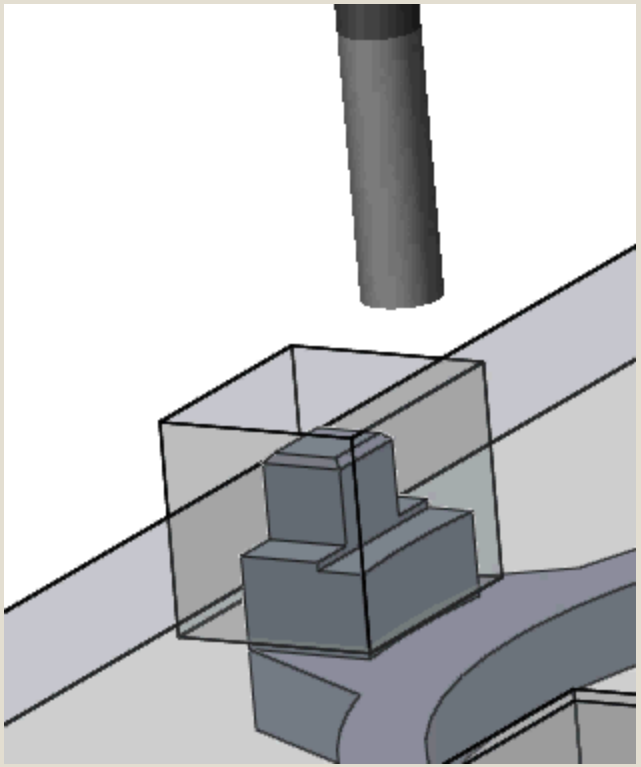

- Oil delivery circuit and BPC control system

- CAM with HSMXpress

CAM = ‘Computer-Aided Manufacturing’

PART 4

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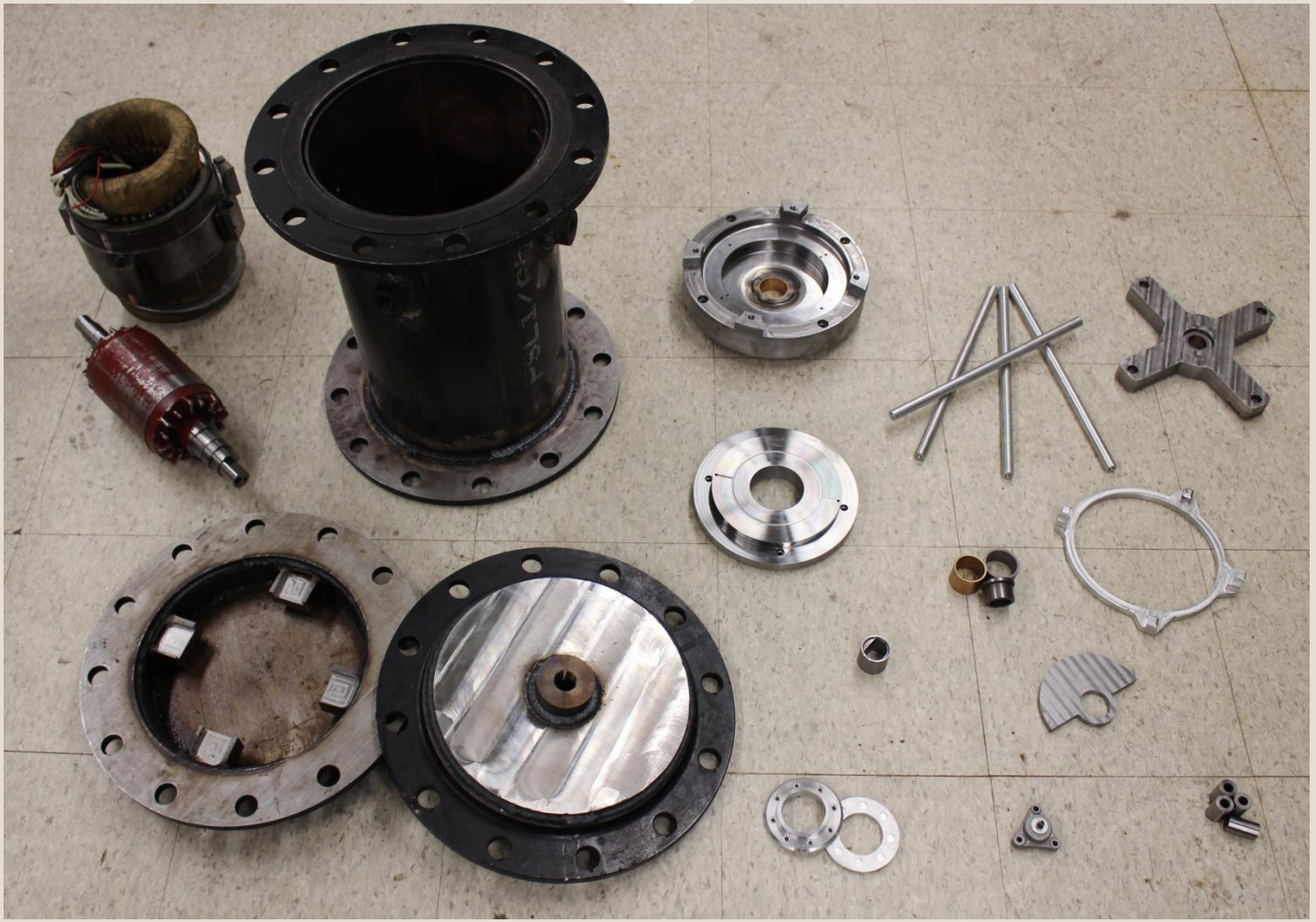
PROTOTYPE FABRICATION AND ASSEMBLY

4. Prototype fabrication and assembly



4. Prototype fabrication and assembly

4. Prototype fabrication and assembly

PART 5

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CONCLUSION AND PERSPECTIVES

5. Conclusion & Perspectives

- Finish the single-stage prototype
  - Check the envelope sealing
  - Instrumentation
  - Oil delivery circuit & BPC circuit piping
- Experimental test and validation
  - Test rig at Eckerd College (FL)
  - Validate the deterministic model
  - (Update the second stage geometry)
- Design and fabrication of the two-stage prototype

5. Conclusion & Perspectives

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Test rig (Eckerd College – FL)

Collectors

Condenser

ORC unit

HTF tank

5. Conclusion & Perspectives

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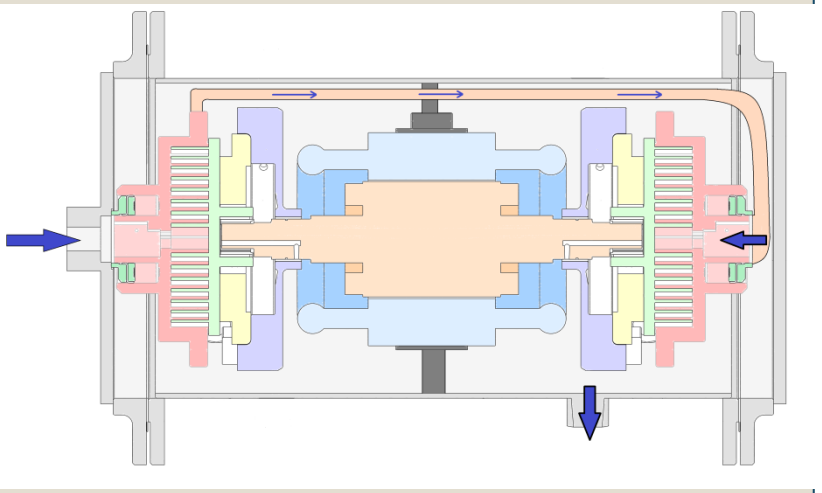

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Thank you for your attention

QUESTIONS ?

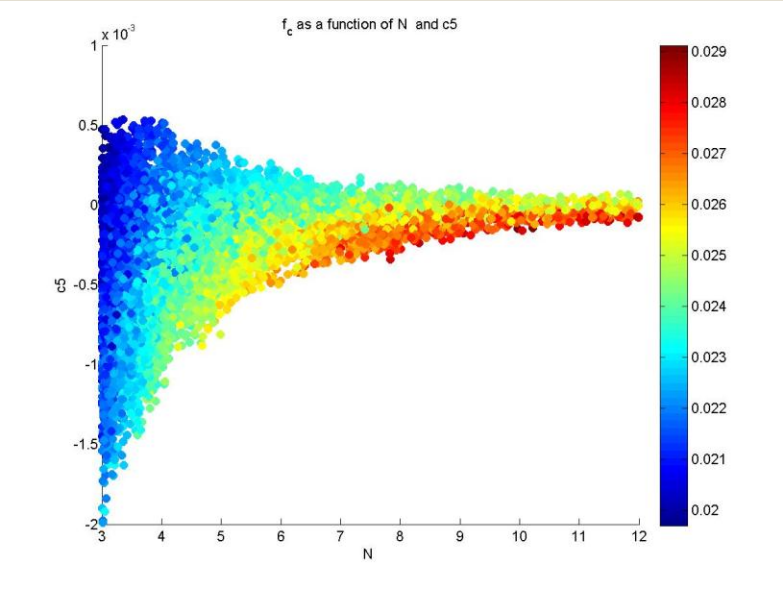
More information : *Design and fabrication of a variable wall thickness two-stage scroll expander to be integrated in micro-solar power plant* - Master thesis – Rémi DICKES

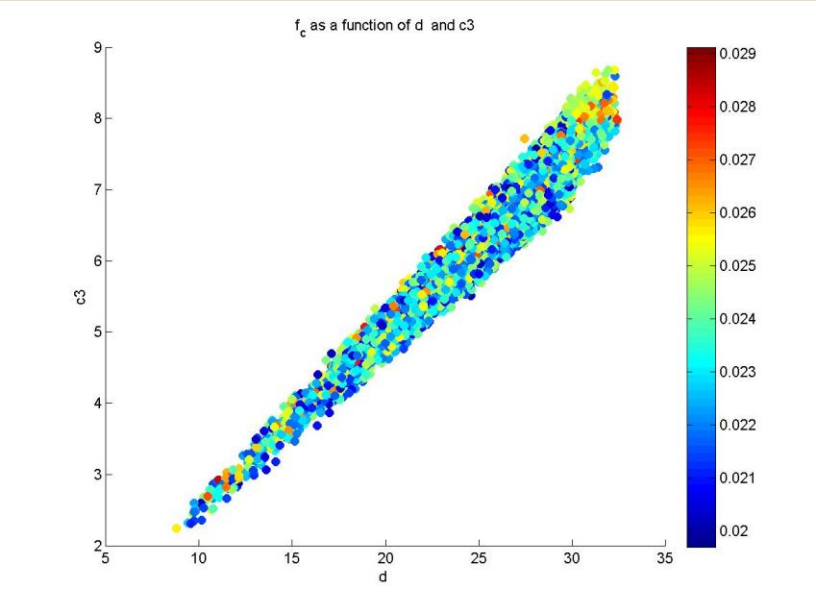
APPENDIX

Variable wall thickness geometries ➔ Danfoss frame

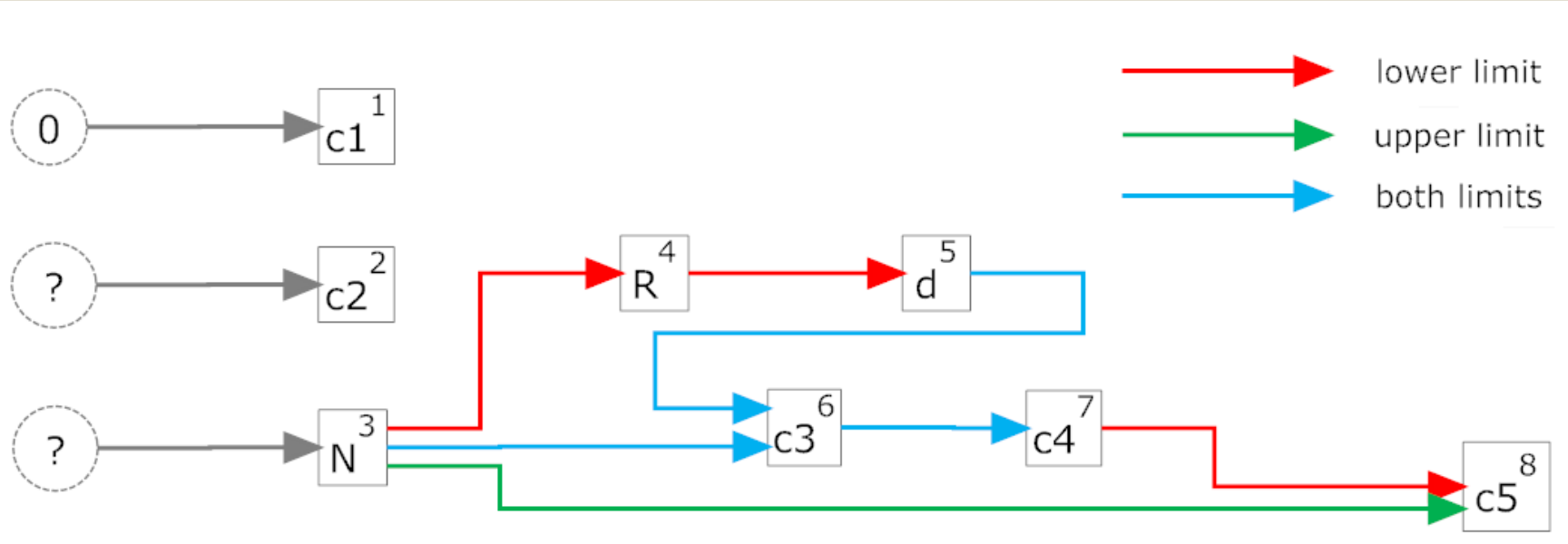
- 1 geometry ⇔ 8 parameters
  - $s_x = c_1 + c_2\,\varphi + c_3\,\varphi^2 + c_4\,\varphi^3 + c_5\,\varphi^4$
  - R, d and N
- Warning : non reversible process! ➔ random generation
- Select the best candidates among a database
- All parameter combinations are not viable
  - Only exploring viable parameter domains
  - Using a hierarchical parameter selection strategy

APPENDIX

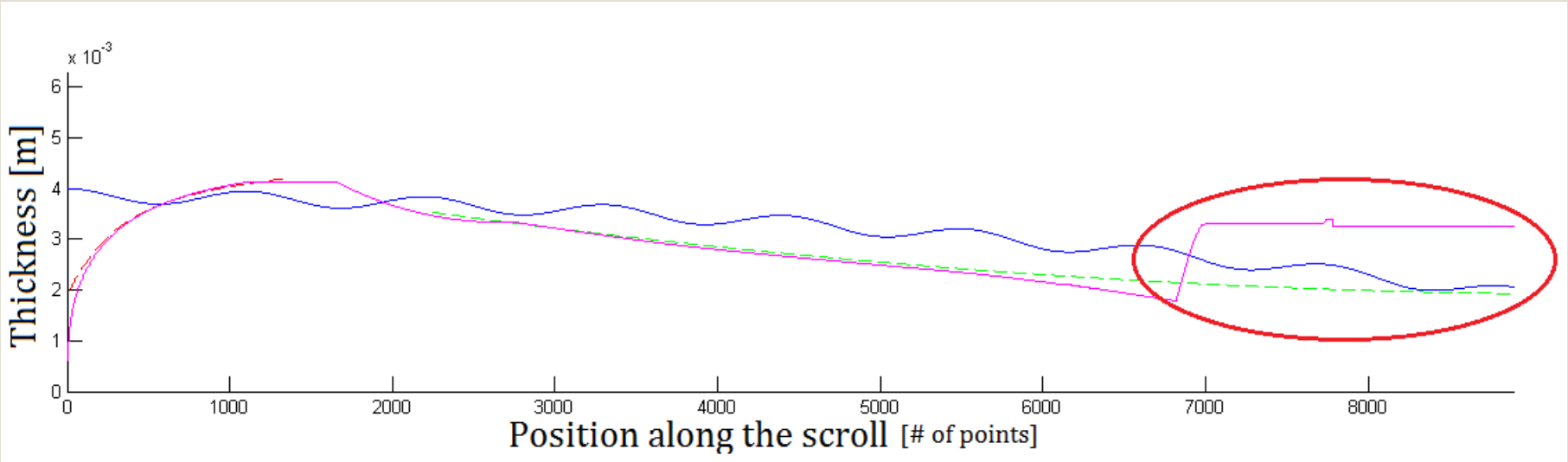

f_c as a function of N and c5
x 10^-3
1
0.5
0
-0.5
-1
-1.5
-2
c5
3
4
5
6
7
8
9
10
11
12
N
0.029
0.028
0.027
0.026
0.025
0.024
0.023
0.022
0.021
0.02


f_c as a function of d and c3
9
8
7
6
5
4
3
2
c3
5
10
15
20
25
30
35
d
0.029
0.028
0.027
0.026
0.025
0.024
0.023
0.022
0.021
0.02

APPENDIX


lower limit
upper limit
both limits
0
c1
1
?
c2
2
?
N
3
R
4
d
5
c3
6
c4
7
c5
8

APPENDIX


x 10^-3
Thickness [m]
0
1
2
3
4
5
6
0
1000
2000
3000
4000
5000
6000
7000
8000
Position along the scroll [# of points]