Pressure-volume diagrams of scroll compressors at various operating points

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Danfoss Commercial Compressors

- Leading compressor R&D and manufacturing for commercial air conditioning, heating and refrigeration applications since 1971
- Manufacturing in three continents: Europe, USA, China
- Leading the market in commercial inverter scrolls with prequalified drives
- Danfoss Turbocor Compressors with oil-free, magnetic bearing technology

- **Turbocor**: 60-200TR
- **Scroll**: 3 - 10 Hp
- **Reciprocating**: 1.5 - 13 Hp
- **Scroll**: 9-40 Hp
- **Scroll**: 3 - 30 Hp
## Air conditioning Applications

### Compressors platforms

<table>
<thead>
<tr>
<th>Power Range</th>
<th>Danfoss Scrolls</th>
<th>Danfoss Maneurop recip.</th>
<th>Danfoss Inverter Compressors</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10TR - 35 kW</td>
<td>H (HRH, HLJ, HCJ, HRP, HLP, HCP)</td>
<td>MTZ/MT</td>
<td>VRJ, VTZ</td>
</tr>
<tr>
<td>8TR-40TR 28-140 kW</td>
<td>S (SH, SZ, SM, SY, WSH)</td>
<td></td>
<td>VSH, VZH</td>
</tr>
<tr>
<td>&gt; 40TR-140 kW</td>
<td>Tandems, trios</td>
<td></td>
<td>Tandems Turbocor</td>
</tr>
</tbody>
</table>

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Motivation

Get detailed knowledge of the compression process

- At design point, and at low and high pressure ratio
- Better understand where and when occur the leakages
- Analyze the backflow or overshoot phenomena
- See the difference between the direct and indirect pockets
- Thinly measure the way Intermediate Discharge Valves work
- Find some directions for their improvement
Instrumentation of the scroll set

Locations of sensors determined in order to have at least one constantly working in each pocket

Instrumentation phase in the laboratory

A gear is mounted on the upper counterweight

Allowing indirect velocity measurement

Gives a reference for the closing/opening of the pockets
ARI point: Evolution of pressures from inlet to discharge
ARI point : PV diagram

- Pressures are recombined to establish the pressure-volume diagram.

It is compared with a theoretical one, based on an assumption of isentropic compression (in red).

The differences between pockets at the end of the compression appear clearly.

Even at design point, overcompression occurs at discharge.
High Pressure ratio point

- Inflexion of the evolution of pressure at discharge.

Very important backflow from the discharge port to the pocket.

Overcompression at the end still exists.

Very high leakages result in a higher difference with the isentropic compression and lower efficiencies.
R410A APPLICATION

Sat Disch Temp °C

Sat Suct Temp °C

Built in PR

Back Flow

High EER zone

Over compression

Light summer conditions for A/C
(could be a large % of the yearly running time)
IDV Principle
Compressor with Intermediate Discharge Valves

- Location of pressure sensors and of valves inside the scroll.

One IDV is instrumented to measure its motion.

The valves can be active or blocked.

It is thus possible to compare the way the machine works with or without them, and to quantify the gain in efficiency they bring.

The motion measurement of the IDV helps to understand how the system can be improved.
Low pressure ratio point with or without IDV

- Evolution of pressure inside the scrolls.
  - with IDV working
  - without IDV

Very effective limitation of overpressure by the valve.
Strong gain in efficiency
A certain overpressure is necessary to open the valves.
Pressure-volume diagrams at low pressure ratio

- Comparison of the PV diagrams with IDV working and without IDV

The IDV allow the machine to run with a good efficiency at points far from the design one. The system could even be improved by reducing mass and stiffness.
## ENER Lot 1 ↔ ENTR Lot 21 - Overview

### ENER LOT1 Heating sys

<table>
<thead>
<tr>
<th>2013 Adoption</th>
<th>2015 Tier 1</th>
<th>2017 Tier 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boilers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP Low T (35°C)</td>
<td>&gt;86%</td>
<td>&gt;86%</td>
</tr>
<tr>
<td>HP High T (55°C)</td>
<td>&gt;115%</td>
<td>&gt;125%</td>
</tr>
<tr>
<td></td>
<td>&gt;100%</td>
<td>&gt;110%</td>
</tr>
</tbody>
</table>

Regulation No. 811/2013

### ENTR LOT21 A/C sys

<table>
<thead>
<tr>
<th>2015 Adoption</th>
<th>2017 Tier 1</th>
<th>2019 Tier 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/W Chiller</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;400kW</td>
<td>&gt;157% (4.0)</td>
<td>&gt;161% (4.1)</td>
</tr>
<tr>
<td>&gt;400kW</td>
<td>&gt;173% (4.4)</td>
<td>&gt;185% (4.7)</td>
</tr>
<tr>
<td>W/W Chiller</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;400kW</td>
<td>&gt;196% (5.1)</td>
<td>&gt;200% (5.2)</td>
</tr>
<tr>
<td>&gt;400kW</td>
<td>&gt;256% (6.6)</td>
<td>&gt;272% (7.0)</td>
</tr>
<tr>
<td>A/A Chiller</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;181% (4.6)</td>
<td>&gt;189% (4.8)</td>
<td></td>
</tr>
</tbody>
</table>

\[ \eta\% = \frac{\text{SCOP}}{2.5 - \sum F(i)} \]

\[ \eta\% = \frac{\text{SEER}}{2.5 - \sum F(i)} \]

### Notes

- **A/W Chiller** up to \(\approx 570-600\text{kW}\) cooling capacity (A35/W7), in reversible mode,
  → up to **400kW** (-30%) heating capacity (A-10/W35)
  → falls into the requirements of ENER Lot 1 for LOW T HPs

- **High Temp HP application** (A-10/W55) is not achievable with standard A/C compressors (map limitation)
  → All HPs with reversibility function falls into the requirements of ENTR Lot 21

SCOP or SEER per EN14825

\[ F(i) = -3\% \text{ for A/W, B/W & W/W if w/out thermostat} \]

\[ -5\% \text{ for B/W & W/W due to water pump losses} \]
A/W Reversible Chiller
Design Configuration „GOOD“

<table>
<thead>
<tr>
<th>SEER</th>
<th>SCOP</th>
<th>(°C)</th>
<th>1C</th>
<th>1C</th>
<th>2C</th>
<th>2C</th>
<th>1C</th>
<th>2C</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3.81</td>
<td>3.99</td>
<td>4.17</td>
<td>4.06</td>
<td>3.98</td>
<td>4.04</td>
<td>3.80</td>
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<td></td>
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<td>3.80</td>
<td>3.95</td>
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**Reversible**

- **Low Temp. heating mode**

A/W Reversible Chiller
Design Configuration „GOOD“

- TDE=3K
- TDC=15K
- Asymmetric PHX w/ low water side pressure drop
- PHX counter-flow in cooling mode
- Variable Outlet Water Temp.: 7-11.5 °C
- Full Load cap. derating: -5% (manifolding, suct. acc., 4Way)
- Part Load cap. derating: -1.5%
- AC condensing fans PWM modulated down to 50% speed
- AC-fan power= 9.5% compressor power @ full load

**<400kW IDV** technology brings A/W chillers well above Tier 2 levels
- The tandem configuration is still weak and requires a more robust system design or different tech (Variable Speed)
- >400kW targets are very high and only Trio 2C w/ IDV gets close to Tier 1
- More robust sys design required (EC fans, lower TDE/TDC, ...). **IDV** tech allows for less drastic/expensive sys changes

**SCOP Low Temp** targets not a problem. **IDV** runs at 3-4% points higher than competition and prev. technology

(*) simulation made with 25hp compressors
Conclusion:

- This work brings:
  - Detailed information on the pressure distribution in the scrolls now available.
  - Measurement of indicated efficiencies.
  - Precious for quantifying leakages and losses.
  - Precise estimation of the gain brought by IDV.
  - Large database available to tune computation models.

- The IDV benefit will help to go toward the new EU energy regulation requirement.
THANKS FOR YOUR ATTENTION