Content

• Why VFD
• VFD centrifugal chiller technology
• Solution
HVAC major issues

Energy conservation

Global warming reduction
Why VFD

- No Compressor A/C
- Higher efficiency
- Lower GWP (R1234ze)
- Natural gas (Ammonia, CO$_2$)
Why VFD

AHRI PART LOAD WEIGHTING FACTORS

\[
\text{kW} / \text{TON} \quad = \quad \frac{1}{0.01 + 0.42 + 0.45 + 0.12}
\]

A, B, C & D are the COPs at that % Load

ARI550/590-2003

\[\begin{array}{c|c|c|c|c}
\text{LOAD} & \text{100%} & \text{75%} & \text{50%} & \text{25%} \\
\hline
\text{WEIGHTED%} & 1\% & 42\% & 45\% & 12\%
\end{array}\]
Why VFD

• Cooling system (pump, tower)
• Refrigeration system (compressor)
• Chilled water system (pump)
• Air system (fan)
Why VFD

Improve part load efficiency (IPLV)
VFD Centrifugal Chiller Technology

The compressor world is changing:

Gen 1  | Traditional design
Gen 2  | High-speed gear-drive
Gen 3  | High-speed direct-drive + VFD

- Compact size
- Efficiency (no gears, fewer bearings, permanent magnet motors)
- IPLV (variable speed)
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Increasing compressor speed drives motor development:

Gen 1
Traditional induction motor

Gen 2
High-speed induction motor

Gen 3
Permanent Magnet motor

Compact size
Efficiency
VFD Centrifugal Chiller Technology

Increasing compressor speed drives bearing development:

- Oil-lubricated sleeve bearings
- Oil-lubricated ball bearings
- Magnetic bearings
- Ceramic ball bearings
- Gas bearings
- Foil bearings
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Traditional gear-drive chiller

- Economizer
- Condenser
- Two stage compressor
- Gear box
- 50/60 Hz motor
- Control panel
- Evaporator
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Traditional gear-drive compressor

Two bearings on high-speed compressor shaft

Two bearings on low-speed motor shaft
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Traditional gear-drive compressor

This is an inline design –

The second stage impeller follows and is inline with the first stage impeller. A deswirl section lies between the two stages to increase pressure and align the flow with the second stage impeller.

This is an overhung design –

The lengthy flow path lies outside of the high-speed shaft bearings. This requires careful rotordynamic analysis.
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• What are the design features of a high-speed direct-drive compressor?
VFD Centrifugal Chiller Technology
Initial inline concept for high-speed direct-drive compressor

Inline, overhung compressor section

High-speed motor with two bearings
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• There are basically two paths to creating a high-speed direct-drive compressor –

1. Simply replace the low speed motor and gear set with a high speed motor on the compressor shaft

2. Design a new flow path with back-to-back impellers on each end of a central high-speed motor

• In either case a VFD is required to provide the compressor speed, and this automatically provides improved part load performance as an inherent feature of the design concept

• After studying both options, we chose the second path because of better efficiency, balanced thrust forces, and robust rotordynamics
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• Initial inline concept for high-speed direct-drive compressor

• This concept simply replaces the low speed motor and gear set with a high-speed motor directly on the compressor shaft

• However, this is not the design concept that was finally chosen. Considerations included -

1. Efficiency
2. Balanced thrust forces
3. Rotordynamics
4. Complexity of interstage castings
**VFD Centrifugal Chiller Technology**

New high-speed direct-drive chiller

- Compressor
- Evaporator
- Condenser with integral economizer
- VFD
- Control panel
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- Evaporator with top feed for falling film
- Condenser with integral economizer
- Crossover pipe from first stage volute to second stage inlet
- Discharge to condenser
- Compressor with central motor and back-to-back impellers
- Suction elbow
- Evaporator with top feed for falling film

Condenser with integral economizer
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- First stage inlet from evaporator
- First stage volute
- Crossover pipe from first stage volute to second stage inlet
- Second stage volute discharges to condenser
- First stage inlet from evaporator
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7 Patents

250RT ~ 550RT, 120Hz ~ 300Hz

Low overhung mass, good rotordynamics, balanced thrust forces
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- IGV
- 1st Stage Impeller
- 1st Bearing
- 1st Seal
- Motor Stator
- Motor Rotor
- 2nd Seal
- 2nd Bearing
- 2nd Stage Impeller
- 1st vaneless diffuser and volute
- 2nd vaneless diffuser and volute
- 2nd Stage Inlet
**VFD Centrifugal Chiller Technology**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High efficiency impeller</strong></td>
<td>Full 3D flow impeller</td>
</tr>
<tr>
<td></td>
<td>Backward blade design</td>
</tr>
<tr>
<td></td>
<td>Efficiency &gt; 97%</td>
</tr>
<tr>
<td><strong>Gas reflux technology</strong></td>
<td>No need blade</td>
</tr>
<tr>
<td></td>
<td>Gas flux in big U shape channel</td>
</tr>
<tr>
<td></td>
<td>Evenly gas mixing</td>
</tr>
<tr>
<td><strong>Gas from economizer</strong></td>
<td>Less amount gas flow</td>
</tr>
<tr>
<td></td>
<td>Decrease temp in the second stage</td>
</tr>
<tr>
<td></td>
<td>Less power consumption</td>
</tr>
</tbody>
</table>
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2 Bearings instead of 4.

NO Gear/Mechanical loss.
VFD Centrifugal Chiller Technology

Typical design

- Unique Self-Balanced thrust forces Structure
- Less axial load (10%) on bearing
- Less mechanic loss
- Small shaft size

Midea design
VFD Centrifugal Chiller Technology

- High power density and small size, with size only 20% of AC inverter motor.
- Designed based on speed and high-frequency operation, variable frequency 120~300Hz.
- Motor efficiency as high as 95.5%.
VFD Centrifugal Chiller Technology

- 360° Refrigerant cooling system;
- 3 X PTC sensor to protect the motor;
VFD Centrifugal Chiller Technology

- No need hot gas bypass, higher efficiency and lower noise level on AHRI condition.
- Capacity load from 10%~100% and cooling EWT up to 37 °C are able to satisfy the application requirement of multiple operating conditions.
VFD Centrifugal Chiller Technology

- **Potential benefits:**
  1. Lighter and more compact (smaller motor, no gear)
  2. More efficient (two bearings instead of four, no gear loss. More efficient crossover with central motor back-to-back design)
  3. Excellent part load performance due to VFD
  4. More reliable (fewer mechanical components)
  5. Excellent platform for future bearing developments

- **Potential disadvantages:**
  1. Requires a VFD
VFD Centrifugal Chiller Technology

Oil-free

<table>
<thead>
<tr>
<th>Product</th>
<th>TT300 R134a</th>
<th>TT350 R134a</th>
<th>TT400 R134a</th>
<th>TT500 R134a</th>
<th>TG310 R1234ze</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Speed (RPM)</td>
<td>40,000</td>
<td>35,000</td>
<td>29,000</td>
<td>23,000</td>
<td>35,000</td>
</tr>
<tr>
<td>Max Pressure ratio</td>
<td>4.8 Model dependent</td>
<td>5.2</td>
<td>3.5</td>
<td>3.5</td>
<td>5.2</td>
</tr>
<tr>
<td>Applications</td>
<td>Air / Water Cooled</td>
<td>Air/Water Cooled</td>
<td>Water Cooled</td>
<td>Water Cooled</td>
<td>Air / Water Cooled</td>
</tr>
<tr>
<td>Refrigeration capacity (Tons &amp; KW)</td>
<td>60/90 210/315</td>
<td>90/120 315/420</td>
<td>120/150 420/525</td>
<td>160/180 560/630</td>
<td>60/85 210/297</td>
</tr>
</tbody>
</table>

- Sustainable energy efficiency
- Oil-free
- Variable speed
- Compact
- Quiet
- Less mechanical complexity
- Less maintenance
- Greater value
VFD Centrifugal Chiller Technology

Oil-free

- Integral VFD
- Magnetic bearings and sensors
- Permanent magnet brushless DC motor
- Heat exchanger for motor cooling (refrigerant cooled motor/VFD)
- Compressor control module
- Discharge Port
- Inlet Guide Vanes
- Suction gas
- Shaft & impeller
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Evaporator

DX → Flooded

Full Falling Film

Falling Film
VFD Centrifugal Chiller Technology

Flooded evaporator

Dry vapor to compressor

Tube bundle

Filter to remove liquid droplets

Liquid distributor

Water flow

Liquid inlet
VFD Centrifugal Chiller Technology

Flooded evaporator

- Liquid inlet
- Dry vapor to compressor
- Liquid level in shell, optimized so that boiling action just wets the top tubes for maximum performance
- Large vapor space so low velocity flow will not carry liquid droplets into compressor
- Flow is distributed evenly along the length of the shell

Water flow
VFD Centrifugal Chiller Technology

Falling film evaporator

- Baffle to remove liquid droplets
- Vapor path for generated vapor
- Tube bundle
- Dry vapor to compressor
- Liquid distributor above top row of tubes
- Lower tube bundle to evaporate any remaining liquid
- Liquid inlet
- Water flow
VFD Centrifugal Chiller Technology

Falling film evaporator

Baffle and vapor space around distributor designed to minimize carryover of liquid droplets to compressor

Vapor must exit the tube bundle and flow around the tube bundle

Liquid level in shell

Dry vapor to compressor

Liquid inlet

Water flow
VFD Centrifugal Chiller Technology

Falling film evaporator
VFD Centrifugal Chiller Technology

Falling film evaporator

Distributor design is critical to the success of this concept

End feed with tapered shape to distribute flow evenly along the length of the tube bundle

Structural stiffeners

Baffles to control vapor flow (next slide)

Perforated plate to spread flow evenly

Hole pattern to match the tube spacing so flow is delivered to the top of each tube row
VFD Centrifugal Chiller Technology

- Distributor design is critical to the success of this concept

Falling film evaporator

- Here is the second generation design:

Suction baffle with varying openings to provide uniform vapor flow along the length of the shell. The compressor will tend to pull vapor preferentially from the region directly below the suction unless there is a variable restriction (see previous slide)

Distributor baffles to separate liquid droplets from vapor flow

Vapor flow paths are not shown in this illustration
VFD Centrifugal Chiller Technology

Falling film evaporator

- Distributor design is critical to the success of this concept

- Second generation design -
  1. Fewer parts that are simpler to manufacture and assemble
  2. Incorporates important flow control baffles into the design
VFD Centrifugal Chiller Technology
Falling film evaporator

• How well does this design concept work?
VFD Centrifugal Chiller Technology
Falling film evaporator

This test data shows that, if a proper film is developed, all the tubes in the column will have equal heat transfer coefficient.

Above a minimum flow rate, the heat transfer coefficient is very constant.

Heat transfer coefficient for each tube in a vertical column of tubes

Figure 14.19. Falling film on a single-row of ten Wolverine Turbo-BII tubes from Roques and Thome (2007a) showing odd row results.
VFD Centrifugal Chiller Technology

Falling film evaporator
VFD Centrifugal Chiller Technology

Falling film evaporator

- Potential benefits:

1. Reduction in working fluid to about 1/3 of flooded evaporator
2. Better heat transfer performance
3. More uniform heat transfer throughout the evaporator
4. Lower approach temperature
5. More compact evaporator design
6. Improved oil removal (oil holds up in a flooded bundle but drains to the bottom of a falling film evaporator)
VFD Centrifugal Chiller Technology

Falling film evaporator

- Charge optimization

ITD/ΔT or Approach

Optimum charge is where the curve flattens out

Refrigerant charge/flow rate

ITD = inlet water temperature – saturation temperature
ΔT = inlet water temperature – outlet water temperature
Approach = outlet water temperature – saturation temperature
Solution

Features:
✓ Excellent Efficiency: COP up to 6.40, IPLV up to 10.70

✓ High Reliability compressor: VFD back-to-to direct-drive centrifugal

✓ Lower Noise: low to 73 dB(A)

✓ Double longer Warranty

✓ Green: R134a & Full falling film tech. reduce up to 40% refrigerant charge.

250RT ~ 550RT

VFD Direct-Drive Centrifugal chiller
Solution

Features:
- Excellent Efficiency: COP up to 6.34, IPLV up to 11.22
- Oil free centrifugal compressor:
- Lower Noise: low to 73 dB(A)
- Double longer Warranty
- Green: R134a & Full falling film tech. reduce up to 40% refrigerant charge.
- Less Maintenance

150RT ~ 700RT
Thank You!