Use of Variable Frequency Drives (VFDs) With Copeland Scroll™ and Copeland Discus™ Fixed Capacity Compressors in Refrigeration Applications

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Revision Tracking R4

Pg. 2 – Scroll compressors included on last
paragraphs of Instruction section.
Pg. 2 - Pag. 3 – Safety Instructions added.
Pg. 5 – “Voltage” word added to 5 Section title.
Pg. 5 – Description of effect on Scroll performance
added in Section 7.
Pg. 5 – Details about control signal of VFD added.
Pg. 5 - Pag. 6 – Safety signs added to the text.
Pg. 6 – Recommendation of switching frequency of the
VFD (2 to 3 kHz) added to Section 11.
Pg. 6 – Compliance with IEC Technical Specification
60034-17 added to Section 11.
Pg. 6 – Explanation about short separation between
VFD and compressor added to Section 11.
Pg. 7 – Reference to 70 Hz for Scroll deleted.
Pg. 7 – “General Guidelines and More Information”
Section added.
Pg. 7 – Section related to Control Techniques VFD
deleted.
Pg. 7 – Typical VFD Parameter list modified following
suggestions from Engineering Group.
Pg. 8 – FVD voltage waveform graphic added.
Pg. 9 – Specific VFD connection deleted.

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Safety Instructions

Copeland™ compressors are manufactured according to the latest U.S. and European Safety Standards. Particular emphasis has been placed on the user's safety. Safety icons are explained below and safety instructions applicable to the products in this bulletin are grouped on Page 3. These instructions should be retained throughout the lifetime of the compressor. You are strongly advised to follow these safety instructions.

Safety Icon Explanation

- **DANGER**: indicates a hazardous situation which, if not avoided, will result in death or serious injury.

- **WARNING**: indicates a hazardous situation which, if not avoided, could result in death or serious injury.

- **CAUTION**: used with the safety alert symbol, indicates a hazardous situation which, if not avoided, could result in minor or moderate injury.

- **NOTICE**: is used to address practices not related to personal injury.

- **CAUTION**: without the safety alert symbol, is used to address practices not related to personal injury.

- **FLAMMABLE**
Instructions Pertaining to Risk of Electrical Shock, Fire, or Injury to Persons

<table>
<thead>
<tr>
<th><strong>WARNING</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ELECTRICAL SHOCK HAZARD</strong></td>
</tr>
<tr>
<td>• Disconnect and lock out power before servicing.</td>
</tr>
<tr>
<td>• Discharge all capacitors before servicing.</td>
</tr>
<tr>
<td>• Use compressor with grounded system only.</td>
</tr>
<tr>
<td>• Molded electrical plug must be used when required.</td>
</tr>
<tr>
<td>• Refer to original equipment wiring diagrams.</td>
</tr>
<tr>
<td>• Electrical connections must be made by qualified electrical personnel.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>WARNING</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PRESSURIZED SYSTEM HAZARD</strong></td>
</tr>
<tr>
<td>• System contains refrigerant and oil under pressure.</td>
</tr>
<tr>
<td>• Remove refrigerant from both the high and low compressor side before removing compressor.</td>
</tr>
<tr>
<td>• Never install a system and leave it unattended when it has no charge, a holding charge, or with the service valves closed without electrically locking out the system.</td>
</tr>
<tr>
<td>• Use only approved refrigerants and refrigeration oils.</td>
</tr>
<tr>
<td>• Personal safety equipment must be used.</td>
</tr>
<tr>
<td>• Failure to follow these warnings could result in serious personal injury.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>WARNING</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BURN HAZARD</strong></td>
</tr>
<tr>
<td>• Do not touch the compressor until it has cooled down.</td>
</tr>
<tr>
<td>• Ensure that materials and wiring do not touch high temperature areas of the compressor.</td>
</tr>
<tr>
<td>• Use caution when brazing system components.</td>
</tr>
<tr>
<td>• Personal safety equipment must be used.</td>
</tr>
<tr>
<td>• Failure to follow these warnings could result in serious personal injury or property damage.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>CAUTION</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COMPRESSOR HANDLING</strong></td>
</tr>
<tr>
<td>• Use the appropriate lifting devices to move compressors.</td>
</tr>
<tr>
<td>• Personal safety equipment must be used.</td>
</tr>
<tr>
<td>• Failure to follow these warnings could result in personal injury or property damage.</td>
</tr>
</tbody>
</table>

**Safety Statements**

- Refrigerant compressors must be employed only for their intended use.
- Only qualified and authorized HVAC or refrigeration personnel are permitted to install commission and maintain this equipment.
- Electrical connections must be made by qualified electrical personnel.
- All valid standards and codes for installing, servicing, and maintaining electrical and refrigeration equipment must be observed.
1. Introduction

Variable frequency drives (VFDs) are used to vary the speed of motors and in this way, can be used to control the capacity of a compressor. For refrigeration users they can be an effective method of accurately matching compressor capacity to a load requirement. A method of reducing compressor output is needed in almost every application. With the emphasis today on saving energy by reducing head pressures, an effective capacity control method can bring enormous benefits. Without the means to run efficiently at low capacity, compressor cycling by switching on/off is most commonly used. This method introduces large fluctuations and high power consumption due to heavily loaded heat exchangers. Multiple compressor solutions overcome this problem to some extent and stepping by means of cylinder unloading in piston compressors or scroll unloading in digital scroll compressors can be used to match capacity with some system efficiency gain.

The advantages of varying compressor speed are:

- The load is more closely matched with minimal variation in evaporating pressure and fluctuations in load temperature are minimized.
- Better system efficiency at part load
- Extended lifetime of equipment due to continuous operation instead of cycling
- Low starting current avoids the need for assisted start devices
- With controlled speed increase from standstill there is less risk of sudden liquid or oil return to the compressor on start up

The objective of this bulletin is to provide technical guidelines to developers, designers or installers that intend to use VFDs to vary the speed of Copeland Discus™ and Copeland Scroll™ compressors, originally designed as fixed-speed compressors, in their refrigeration systems.

2. Operation of a Variable Frequency Drive

A VFD works by converting the input alternating current to direct current and, from this, generating an alternating current output at varying frequencies. A compressor driven by a squirrel cage induction motor will run at a speed in direct proportion to the fundamental frequency driving the compressor minus a small amount for motor slip.

3. Evaluation and Important Considerations

Most VFDs can generate frequencies from 2.5 Hz to over 300 Hz. This is well outside the range of any refrigeration compressor; therefore, practical limits must be established.

These limits arise from many different aspects of the compressor design including the capability of the oil pump to maintain lubrication at low speed, motor cooling considerations, and increased losses at higher speeds which can result in less efficient operation and compressor overheating (high discharge temperatures).

The steady state power absorbed by a compressor operating with a VFD will always be more than for a direct line-connected compressor running at the same speed. It is important to choose a high quality VFD because the VFD absorbs a certain amount of power, which will lower the system efficiency. Also, the typical pulse width modulated (PWM) waveform output from the VFD to the motor contains high-frequency harmonics, resulting in increased motor losses.

When considering a VFD, the following points should be taken into account:

- Loss of efficiency unless care is taken with system design and control
- Conventional capacity control methods may not be used with a VFD (i.e. blocked suction, or Copeland Digital) on the same compressor
- Vibration resonance may occur at certain speeds and these are very difficult to predict.
- Risk of electrical disturbance to control signals due to the high-frequency content of the drive’s output waveforms
4. Limits of Use With Copeland Fixed-Capacity Compressors

With many VFDs it is very easy to alter the maximum and minimum output frequencies and the frequency range, so care must be taken to ensure the frequencies are correctly adjusted to prevent damage to the compressor. See Table 1 below for the approved operating frequency range for Copeland fixed-capacity Compressors.

Note: In most variable frequency drives, you can also program "skip" frequencies to avoid vibration resonance that may occur at certain speeds.

<table>
<thead>
<tr>
<th>Model Family</th>
<th>Speed Range</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D, 4D &amp; 6D</td>
<td>25 – 60 Hz</td>
<td></td>
</tr>
<tr>
<td>Refrigeration Scroll (ZB, ZS, ZF) other than those listed below</td>
<td>45 – 60 Hz</td>
<td></td>
</tr>
<tr>
<td>ZB06KAE</td>
<td>50 – 60 Hz</td>
<td></td>
</tr>
<tr>
<td>ZB07KAE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZB08KAE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZRHV72KJE</td>
<td>Per AE4-1343</td>
<td></td>
</tr>
<tr>
<td>ZBH45KJE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1- Approved operating range for fixed-capacity Copeland compressors

Note: Application Engineering Bulletin AE4-1343 should be referenced when applying the ZRHV72KJE and ZBH45KJE variable speed horizontal Copeland Scroll compressors.

5. Approved Voltage/Frequency Ranges With Standard Motors

For the compressors listed in Table 1, the ratio of voltage/frequency (V/f) must be kept constant. For example, a 460V 60Hz motor will only require 383V at 50 Hz according to the constant V/f rule, and can be safely operated at all conditions over the frequency range given in Table 1 with a suitable drive. See Figure 1 for a graphical representation.

Note: On most drives, the output voltage from the drive cannot exceed the input voltage to the drive.

6. Minimum Speed

**CAUTION**

The minimum allowable frequency for Discus and scroll compressors is per Table 1.

**CAUTION**

Note: The 2D family of Discus compressors is limited to fixed 50/60 hertz applications. The vibration issues are too severe when running the 2D below 50 Hz.

7. Effect of the VFD on Performance and Power Input

The compressor capacity can be calculated as being in direct proportion to the speed. A compressor is designed to have optimum pumping efficiency at its nominal speed, usually 1750 RPM for Discus and 3500 RPM for scroll. When operating at speeds other than the nominal, the efficiency of a Discus compressor will change because of the behavior of the valve reeds and the change in pressure drop through the valve plate. However, as these tend to balance out, the change in volumetric efficiency is small.

8. Control of VFD Frequency

The signal necessary to control the VFD depends on the type of VFD used. They are commonly controlled by an analog 4 to 20 mA signal, a 0-10 Vdc signal or via a serial communication bus. This signal should respond to changes in the system’s control variable, for example changes in suction pressure or room temperature.

**NOTICE**

Emerson strongly recommends controlling from suction pressure because a response to a temperature signal may lag.

9. Start Contactor Positioning

If a contactor is used to disconnect the VFD from the motor it should be interlocked to only switch when the VFD is off. There should be a contactor on each side of the drive, i.e. between the drive and the supply and between the drive and the compressor motor. They should be interlocked to break the supply side first. When switching on, the motor side contactor should be
made first, contactor on each side of the drive, i.e. between the drive and the supply and between the drive and the compressor motor. They should be interlocked to break the supply side first. When switching on, the motor side contactor should be made first.

When using a VFD bypass, care should be taken to ensure there can be no voltage feedback to the VFD. Therefore when the bypass is in operation, the contactors on either side of the VFD must be open. The contactors should be coordinated such that the both VFD contactors open before the bypass contactor closes.

10. Starting and Ramp Up

A VFD is capable of delivering a soft start, but care must be taken to ensure that stalling does not occur. The VFD must be able to deliver sufficient power at the lower frequencies to ensure that the compressor accelerates to nominal speed in 3 seconds or less. Only general guidance can be given here, because the exact torque requirements will depend on system pressures at the time of start up. start up.

**CAUTION**

Longer ramp up times could result in inadequate lubrication.

11. Electrical Shielding and Voltage Rise

Wiring of the electrical enclosure and the installation must be carefully conducted in accordance with EMC recommendations. High quality, high reliability pressure sensors must be used and it is necessary to follow EMC measures to ensure that the VFD does not disturb the signals from pressure transducers. Suction and high-pressure sensor signals must be noise-free to the controller input. For best results select a VFD with a built-in EMC filter or add the manufacturer's recommended optional filter if it is not a standard component.

Because the pulse-width modulated (PWM) waveform generated by the VFD is built from high-frequency pulses, there is a danger that the rate of voltage rise on an individual pulse could damage the motor insulation system. To minimize the risk of motor problems it is suggested that the VFD be operated at the lowest switching frequency that gives adequate performance. The recommended switching frequency range for the VFD is 2 to 3 kHz. Higher switching frequencies result in higher losses that lower efficiency and can cause motor overheating. See Figure 2.

Regardless of chosen switching frequency, VFDs used to power Copeland compressors must comply with the provisions of IEC Technical Specification 60034-17. In particular, the motor input voltage must meet the limiting curve of admissible impulse voltage (1.35 kV/microsecond curve). These provisions are required to avoid motor insulation breakdown, to limit motor heating, and to prolong motor life.

In addition, good design practice is to keep the distance between the VFD and the compressor as short as possible. The maximum allowable wire length is affected by the switching frequency, wire capacitance and output filtering built into the VFD. Please consult the VFD manufacturer's documentation for determining the allowable wire length. Additionally, the wiring between the VFD and the compressor can generate radiated emissions (electrical noise). Therefore, the system designer should take care to locate control wires away from these power wires. It may be possible to shield the wires from the VFD to the compressor or apply an EMI filter to minimize the radiated noise. Please consult the VFD manufacturer's documentation for more information on shielding, filters and other EMC measures.

12. Vibration

A compressor running at fixed speed imposes vibrations on its associated framework at a set group of frequencies. The framework can be designed such that its natural frequencies differ from the imposed frequencies.

A compressor driven at variable speeds will impose different frequencies at each speed, so the framework design to eliminate vibration throughout the speed range is more complex.
The framework structure should be stiff enough such that its resonant frequencies are above the maximum compressor frequency. Designing with natural frequencies below the minimum speeds called out in Table 1 could lead to vibration problems during start up. Spring mounts should not be used as they have a natural frequency below 65 Hz. As a rule of thumb, the system should be designed or the VFD control should be configured (skip frequencies programmed), such that there is no operation at any resonant frequencies between 20 and 60 Hz.

13. Typical VFD Parameter Set Up for Discus and Scroll Refrigeration Compressors

The following is a list of some recommended control parameters for configuring a VFD.

- minimum frequency per Table 1
- maximum frequency per Table 1
- 3 sec Acceleration ramp to nominal 60 Hz (20 Hz/second) at startup to ensure lubrication
- Motor rated current (A) per compressor data sheet. Typically used for current limit protection.
- Motor Rated Speed: Recommend setting this to synchronous speed to disable slip compensation on drives with this feature. It can be set to nameplate rated speed to enable slip compensation, but the user must verify current increase is not excessive.
- Motor rated voltage per nameplate
- 2 - 3 kHz Switching frequency
- Motor rated frequency per nameplate

- Open loop V/f (V/Hz) control mode
- Impulse voltage (slew rate) of PWM waveform complies with IEC Technical Specification 60034-17 limit of 1.35 kV / microsecond maximum.

Note that other parameters will need to be adjusted to match the control method and frequency set point input type used.

Contact your Application Engineer for additional information related with your specific application design.

General Guidelines and More Information

For general Copeland Scroll compressor information please log in to Online Product Information at Emerson.com/OPI or contact your Application Engineer. For information on other Copeland Brand variable speed compressors, please refer to the Application Engineering bulletins below.

| AE4-1343 | ZRHV72KJE and ZBH45KJE Variable Speed Horizontal Copeland Scroll™ Compressors |
| AE4-1407 | ZPV021*E - ZPV041*E and ZHV021*P - ZHV034*P Copeland Scroll™ Variable Speed Compressors |
| AE4-1414 | ZPV066 & ZPV096 Copeland Scroll™ Variable Speed Compressors |
| AE4-1388 | 20 to 40 Ton ZP*KC and ZR*KC Copeland Scroll™ Air Conditioning Compressors |
Figure 1 - Voltage-Frequency Relationship

Figure 2 – Utility vs VFD voltage waveform

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