Whitepaper

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BOCK®

Danfoss BOCK® CO_2 Compressor Reduces Vibration for Optimal Transcritical Supermarket Refrigeration Performance

Test shows an average 83% reduction in vibration to optimize energy, performance and reliability

Inside a midwestern supermarket's operational challenge:

It is well established that transcritical CO_2 systems offer compelling advantages for supermarket refrigeration—including rewarding energy savings, low refrigerant cost, and environmental sustainability that avoids refrigerant phaseouts.

Transcritical systems using CO_2 potentially offer superior coefficients of performance, higher volumetric cooling capacity, and upwards of 20% energy savings—and higher—than HFCs in warmer climates. Furthermore, CO_2 offers a future-proof solution that avoids refrigerant phaseouts thanks to an ozone depletion potential (ODP) of zero and a global warming potential (GWP) of 1.0. And as a natural, economical refrigerant, CO_2 addresses what the Environmental Protection Agency (EPA), estimates is a 25% average annual loss of refrigerant charge, which could cost a supermarket $15,000 to replace every year.

But it's also well known that in delivering those benefits, transcritical CO_2 systems also introduce unique technical challenges, such as high operating pressures, control complexity, and component-reliability issues.

This white paper discusses recent tests of Danfoss BOCK® CO_2 compressors in a field retrofit installation at an Ohio site experiencing one of the most persistent CO_2 compressor reliability challenges— vibration. Test results show that the Danfoss solution delivered significantly smoother, quieter performance to promote system reliability and efficiency, a solution that can be applied to practically any transcritical CO_2 supermarket refrigeration system operating in warm climates.

Vibration: Causes and consequences

When the causes and consequences of vibration in CO_2 compressors are understood, the value of using an advanced compressor design becomes evident.

In general, two types of vibration are associated with reciprocating compressors: 1) twisting or rotational vibration along the crankshaft occurring at the same frequency as the crankshaft speed, and 2) lateral vibration transmitted from the system through the piping that harmonizes with the frequency of vibration in the piping structure. When frequencies resonate together, vibration is amplified.

Two-cylinder compressors are more prone to vibration. Unbalanced inertial forces during rotational motion are more pronounced in two-cylinder compressors due to fewer and larger moving components. Under high pressure conditions, the power strokes in two-cylinder compressors can produce significant vibration due to low-frequency pressure fluctuations and imbalances. In contrast, four-cylinder compressors with more components and cylinder area more evenly distribute forces across the crankshaft, reducing the effects of imbalance.

Specific frequencies of the variable-frequency drive (VFD) on the lead compressor may also cause high vibration. An operator may try to alleviate the situation by skipping the problem frequency. But this tactic will reduce the functional capacity range of the compressor.

Handling high-pressure compression is critical to a CO_2 compressor's ability to mitigate vibration.

In subcritical cooling cycles, CO_2 undergoes a gas compression phase and liquid condensing phase below the critical temperature and pressure of 31°C (87°F) and 73 bar (1,069 psia), respectively.

In transcritical cycles, CO_2 remains a "supercritical" fluid that doesn't undergo a phase change from gas to liquid in the gas cooler. Above the critical point, discharge pressures can exceed 90 bar (1,303 psi). A booster system is also employed, with high-pressure fluid discharged from the low-temperature compressor into the suction side of the second-stage medium-temperature compressor. In a transcritical system, the gas cooler constantly cools the supercritical fluid to keep it from overheating. Advanced high-pressure expansion valves control fluid introduction into the evaporator. Because transcritical systems can operate in warm climates, they are considered the optimum CO_2 refrigeration solution for supermarket applications. Accordingly, this system design was used in the test case described below.

High-pressure conditions of high-density supercritical fluid present the biggest challenges for CO_2 compressors.

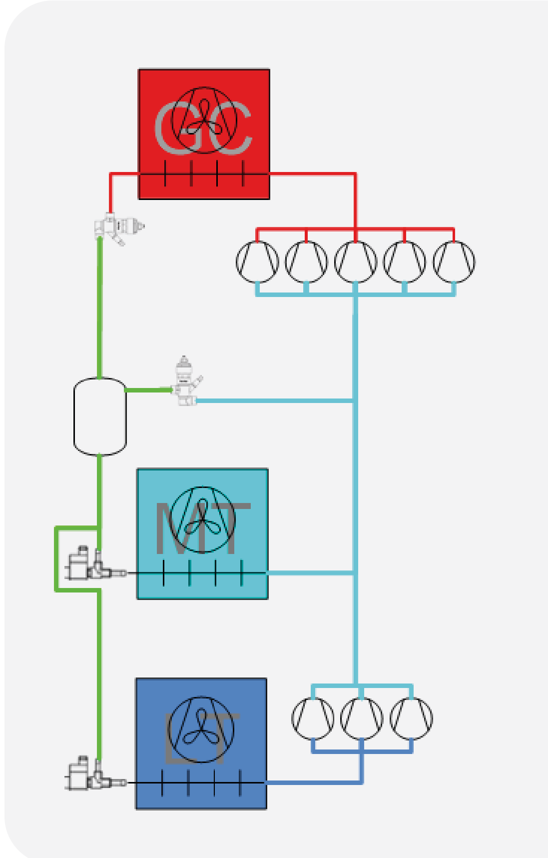


Figure 1 illustrates the basic design of a transcritical booster-system—the system design used in Danfoss BOCK CO_2 compressor vibration test case.

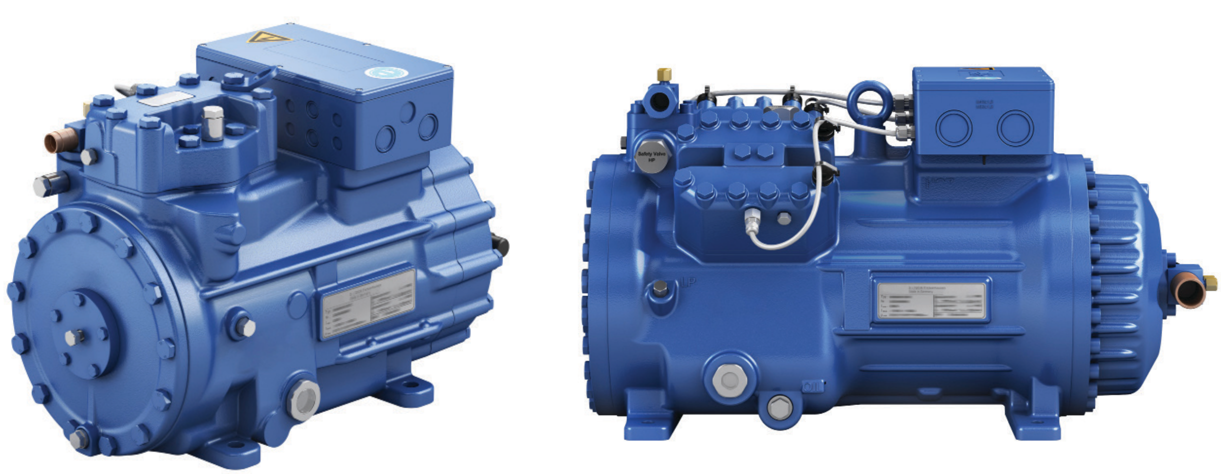


Figure 2 shows (left) one of three Danfoss BOCK HGX22e/130 S 6 CO_2 subcritical semi-hermetic compressors retrofitted into the low-temperature (LT) suction group and (right) one of four HGX34/230 S 35 CO_2 transcritical semi-hermetic compressors retrofitted into the medium-temperature (MT) suction group.

Figure 3 shows the rack retrofitted with three Danfoss BOCK compressors in the low-temperature (LT) suction group (above) and four in the medium-temperature (MT) group installed with proper bracing. The variable frequency drive (left) sets the specific frequencies cited in the accompanying charts.

Operationally, the core function of a reciprocating compressor—suction of refrigerant into the cylinder which is then pushed into the discharge side at high pressure in short, rapid bursts—creates pressure and volume fluctuations inside the cylinders and connecting pipes.

With high-density CO_2 encountered in transcritical cycles, pressure pulses are amplified. The high-amplitude acoustic resonance that occurs, especially at low frequencies, can be transmitted through piping, shaking the entire compressor assembly, including the rack frame. If the pulsation frequency resonates with vibrations in piping or vessels, these disturbances can become extreme. *External vibration issues include* fatigue failure of piping and structural components. The continuous, cyclical loading caused by pulsation-induced forces can cause stress cracks and breakage. In the equipment room, loud, uncontrolled pulsations and vibration can make the operating environment very uncomfortable for personnel.

Vibration issues encountered within the system involve large pressure differences across the suction and discharge sides that can stress valves. Intense vibration can also impair instruments and control systems, affecting system safety and reliability.

Vibration also impacts efficiency when excessive vibration and flow turbulence reduce compression-cycle effectiveness and waste energy.

Danfoss BOCK CO_2 compressors pass the test with an average 83% vibration reduction

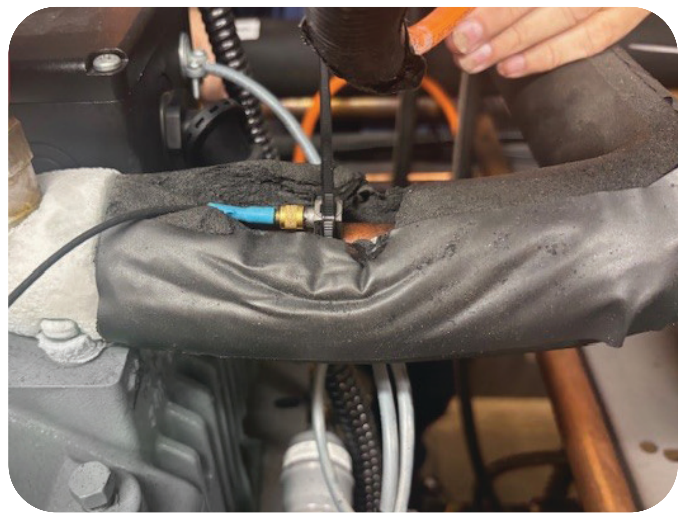
In response to the vibration challenges facing reciprocating compressors in transcritical applications, Danfoss field-tested BOCK semi-hermetic CO_2 compressors at various loads. Gas-cooled BOCK CO_2 compressors, which are UL-certified, are designed for single-stage and cascade systems, as well as for booster systems in medium- and low-temperature subcritical and transcritical applications as tested here (Figure 1).

In this test case, seven Danfoss BOCK HGX series compressors were employed in a transcritical system (Figure 2). All compressors were semi-hermetic and were charged with a synthetic refrigeration oil based on special polyolesters for use with R744 in transcritical applications. The refrigeration rack supplied a total of 1,121kBTUh of cooling.

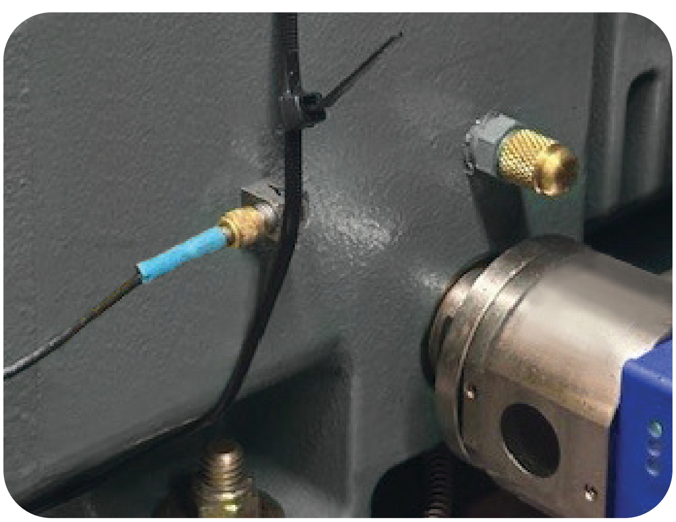
The goal of the project was to test vibration levels at a problem site in a Ohio-based supermarket experiencing abnormal, excessive compressor and rack vibration. *The system was designed* as a transcritical booster system with low-temperature (LT) and medium-temperature (MT) suction groups on one rack, as shown in Figure 3.

In the medium-temperature suction group, four of the four-cylinder BOCK HGX34 compressors were selected. Offering the highest EER/COP values versus competitive products, the performance of HGX34 compressors has been verified by the Association of European Refrigeration Component Manufacturers (ASERCOM). Performance is

↑ Figure 4 shows the LT1 compressor discharge vibration measurement point (see Chart 1).



↑ Figure 5 shows the LT1 compressor suction vibration measurement point (see Chart 2).



↑ Figure 6 shows the LT1 compressor body vibration measurement point (see Chart 3).

↑ Figure 7 shows the LT discharge header vibration measurement point (see Chart 4).

enhanced by using a variable-frequency drive (VFD) that can function in the 20 Hz to 70 Hz range. BOCK compressors also incorporate an internal oil pump with less than 0.2% oil carry over rate for optimal oil circulation. The pump's continuous lubrication helps reduce vibration, compared to traditional splash lubrication. Designed to withstand up to 100 bar (1450 psi) low-temperature (LT) pressure and 150 bar (2175 psi) medium-temperature (MT) pressure, the compressors in this test application operated at 180 to 220 psi LT and 350 to 450 psi MT pressures.

In the low-temperature suction group, three of the two-cylinder BOCK HGX22e compressors were employed.

Main system components included:

- Low Temperature (LT) Suction Group: Three of the two-cylinder model HGX22e/130 S6
- Medium Temperature (MT) Suction Group: Four of the four-cylinder model HGX34/230 S35
- Variable-frequency drive set at specific frequencies for test purposes was applied to the lead compressor
- Gas Cooler
- High Pressure Valve
- Flash Gas Bypass Valve

Typical operating pressure ranges involved:

- Low Temperature (LT) Pressure (180psi-220psi)
- Medium Temperature (MT) Pressure (350psi-450psi)
- Receiver Pressure (490psi-600psi)
- Discharge/Gas Cooler Pressure (700psi-1300psi)

Test method and results

Test setup

For comparison purposes, the rack was retrofitted with seven Danfoss BOCK compressors described above. The area on the rack with the BOCK compressors was properly braced with general piping and discharge piping adjusted according to best practices.

Measurements were captured at multiple locations on the rack and at various points on individual compressors and common piping lines. Measurements were taken as displacement in three directional vectors (X, Y, Z) using a calibrated vibration meter. Because vibration issues were primarily experienced on the low temperature (LT) portion of the system, measurements focused on these areas.

Operating conditions were varied by using different combinations of compressor on/off and lead-compressor frequencies.

Results

Compared to existing compressors, Danfoss BOCK HGX compressors achieved significant vibration reduction ranging from 48.3% to 97.7% at various points and capacities. The average vibration reduction across all capacity combination and direction vectors was 83%. Moreover, the BOCK lead compressor employing the VFD achieved a wider frequency range—from 35-70Hz compared to the original compressor's 40-60Hz range—resulting in a larger capacity range in the suction group without added vibration.

As shown in the accompanying five charts, a set of XYZ measurements were taken on BOCK and competitive compressors occupying the same rack, resulting in six data points for each of three tested frequencies 40 Hz, 50 Hz, and 60 Hz. Each chart represents vibration measurements at one of five different locations: 1) LT1 compressor discharge, 2) LT1 compressor suction, 3) LT 1 compressor body, 4) LT discharge header, and 5) LT compressor discharge for all compressors.

Chart 1:
LT1 compressor discharge vibrations: original (X1, Y1, Z1) vs. BOCK (X2, Y2, Z2) in microns
Average vibration reduction in each direction: X 69.1%, Y 79.5%, Z 48.3%

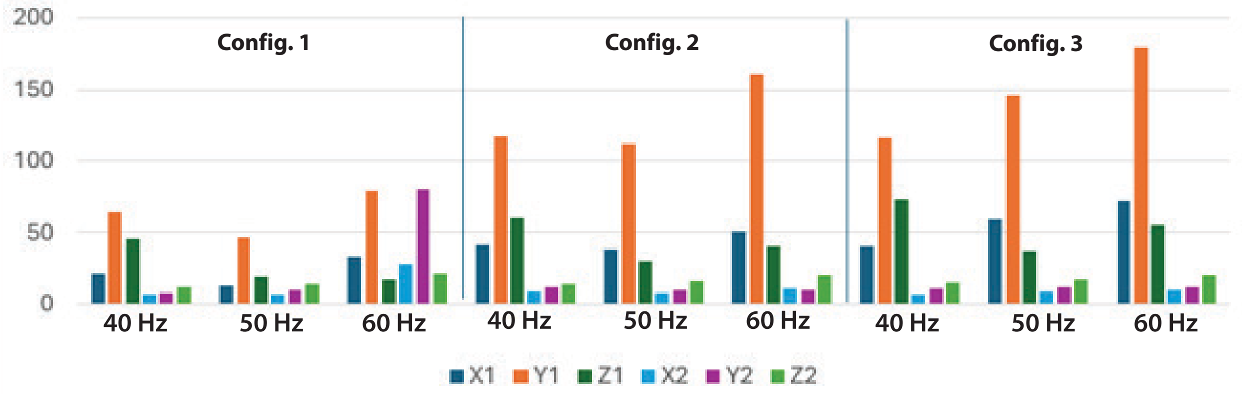


Chart 2:
LT1 compressor suction vibrations: original (X1, Y1, Z1) vs. BOCK (X2, Y2, Z2) in microns
Average vibration reduction in each direction: X 90.9%, Y 71.7%, Z 81.4%

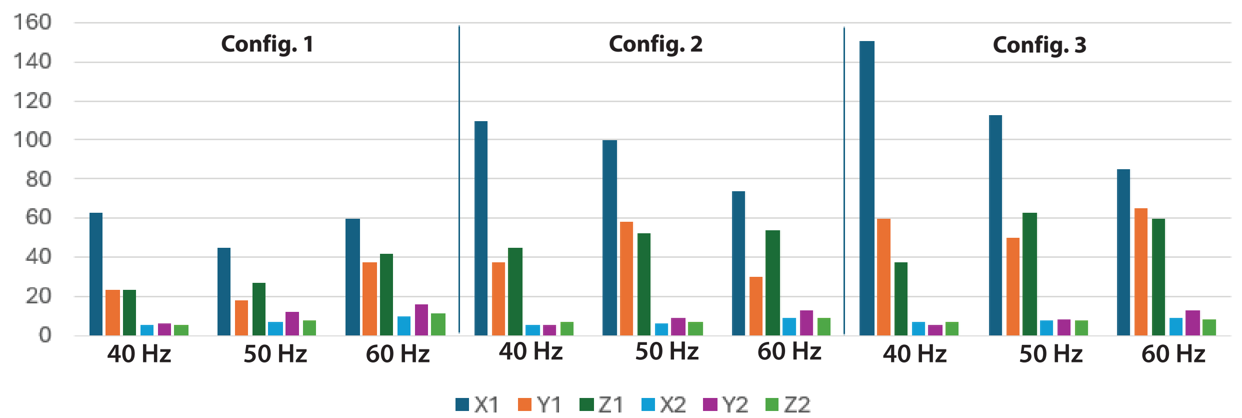


Chart 3:
LT1 compressor body vibrations: original (X1, Y1, Z1) vs. BOCK (X2, Y2, Z2) in microns
Average vibration reduction in each direction: X 84.7%, Y 90.1%, Z 90.0%

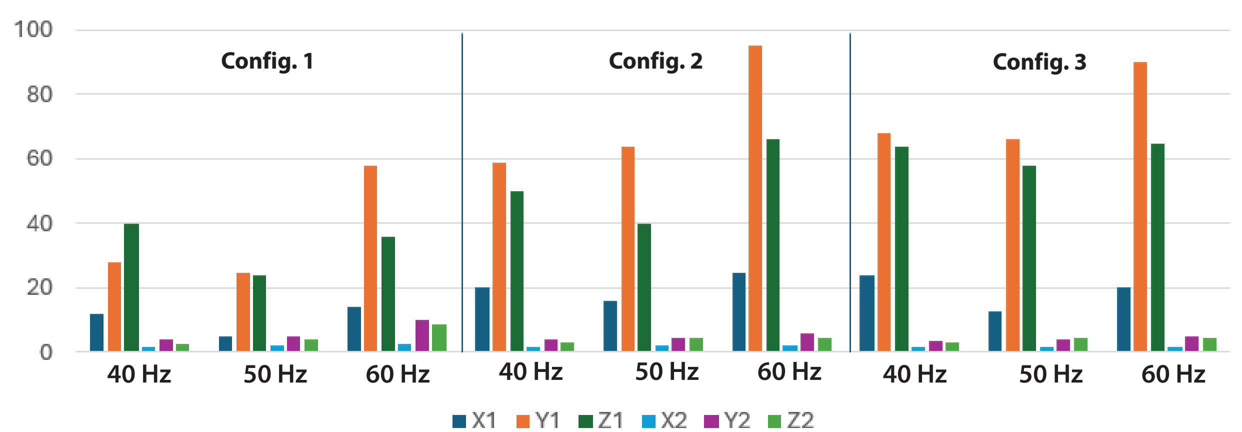


Chart 4:
LT discharge header vibrations: original (X1, Y1, Z1) vs. BOCK (X2, Y2, Z2) in microns
Average vibration reduction in each direction: X 97.7%, Y 97.6%, Z 97.2%

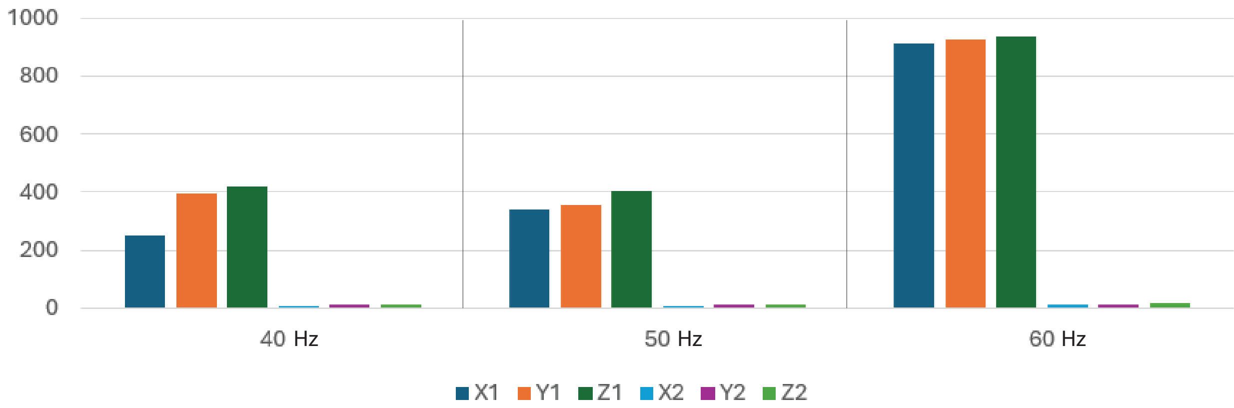
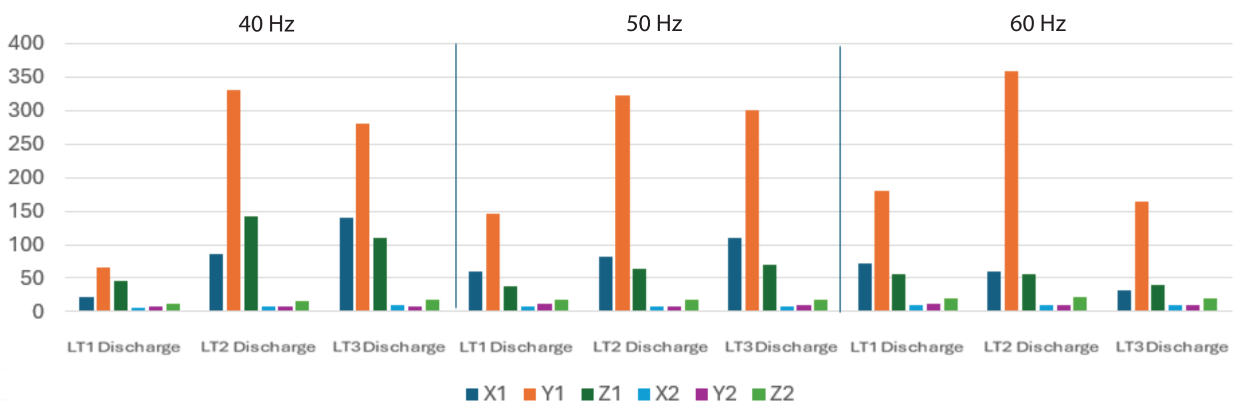


Chart 5:
LT compressor discharge vibrations: original (X1, Y1, Z1) vs. BOCK (X2, Y2, Z2) in microns
Average vibration reduction in each direction: X 84.5%, Y 94.7%, Z 68.9%



Conclusion

Verifying steady performance for dependable energy savings

Along with testing that verified an average 83% reduction in vibration, the subjective benefits were also significant: less noise and less shaking of piping and other rack components which made the operating room environment much more comfortable for personnel. Anticipated future benefits from Danfoss BOCK compressors include enhanced safety, reliability, and performance thanks to stable operation across the various operating pressures typically encountered in a R744 transcritical booster system. Test results indicate that Danfoss BOCK HGX compressors can deliver the energy savings and environmental benefits of CO_2 in a reliable solution for a wide range of supermarket refrigeration sites.

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