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PART 431—ENERGY EFFICIENCY PROGRAM FOR CERTAIN COMMERCIAL AND INDUSTRIAL EQUIPMENT
Subpart T—Compressors

Appendix A to Subpart T of Part 431—Uniform Test Method for Certain Air Compressors

Note: Starting on July 3, 2017, any representations made with respect to the energy use or efficiency of compressors subject to testing pursuant to 10 CFR 431.344 must be made in accordance with the results of testing pursuant to this appendix.

I. Measurements, Test Conditions, and Equipment Configuration

A. Measurement Equipment

A.1. For the purposes of measuring air compressor performance, the equipment necessary to measure volume flow rate, inlet and discharge pressure, temperature, condensate, and packaged compressor power input must comply with the equipment and accuracy requirements specified in ISO 1217:2009(E) sections 5.2, 5.3, 5.4, 5.6, 5.9, and Annex C, sections C.2.3 and C.2.4 (incorporated by reference, see §431.343).

A.2. Electrical measurement equipment must be capable of measuring true root mean square (RMS) current, true RMS voltage, and real power up to the 40th harmonic of fundamental supply source frequency.

A.3. Any instruments used to measure a particular parameter specified in paragraph (A.1.) must have a combined accuracy of ±2.0 percent of the measured value at the fundamental supply source frequency, where combined accuracy is the square root of the sum of the squares of individual instrument accuracies.

A.4. Any instruments used to directly measure the density of air must have an accuracy of ±1.0 percent of the measured value.

A.5. Any pressure measurement equipment used in a calculation of another variable (*e.g.,* actual volume flow rate) must also meet all accuracy and measurement requirements of section 5.2 of ISO 1217:2009(E) (incorporated by reference, see §431.343).

A.6. Any temperature measurement equipment used in a calculation of another variable (*e.g.,* actual volume flow rate) must also meet all accuracy and measurement requirements of section 5.3 of ISO 1217:2009(E) (incorporated by reference, see §431.343).

A.7. Where ISO 1217:2009(E) refers to “corrected volume flow rate,” the term is deemed synonymous with the term “actual volume flow rate,” as defined in section 3.4.1 of ISO 1217:2009(E) (incorporated by reference, see §431.343).

B. Test Conditions and Configuration of Unit Under Test

B.1. For both fixed-speed and variable-speed compressors, conduct testing in accordance with the test conditions, unit configuration, and specifications of ISO 1217:2009(E), Section 6.2 paragraphs (g) and (h) and Annex C, sections C.1.1, C.2.2, C.2.3, C.2.4, C.4.1, C.4.2.1, C.4.2.3, and C.4.3.2 (incorporated by reference, see §431.343).

B.2. The power supply must:

(1) Maintain the voltage greater than or equal to 95 percent and less than or equal to 110 percent of the rated value of the motor,

(2) Maintain the frequency within ±5 percent of the rated value of the motor,

(3) Maintain the voltage unbalance of the power supply within ±3 percent of the rated values of the motor, and

(4) Maintain total harmonic distortion below 12 percent throughout the test.

B.3. Ambient Conditions. The ambient air temperature must be greater than or equal to 68 °F and less than or equal to 90 °F for the duration of testing. There are no ambient condition requirements for inlet pressure or relative humidity.

B.4. All equipment indicated in Table 1 of this appendix must be present and installed for all tests specified in this appendix. If the compressor is distributed in commerce without an item from Table 1 of this appendix, the manufacturer must provide an appropriate item to be installed for the test. Additional ancillary equipment may be installed for the test, if distributed in commerce with the compressor, but this additional ancillary equipment is not required. If any of the equipment listed in Table 2 of this appendix is distributed in commerce with units of the compressor basic model, it must be present and installed for all tests specified in this appendix.

Table 1—Equipment Required During Test

Equipment	Fixed-speed rotary air compressors	Variable-speed rotary air compressors
Driver	Yes	Yes.
Bare compressors	Yes	Yes.
Inlet filter	Yes	Yes.
Inlet valve	Yes	Yes.
Minimum pressure check valve/backflow check valve	Yes	Yes.
Lubricant separator	Yes	Yes.
Air piping	Yes	Yes.
Lubricant piping	Yes	Yes.
Lubricant filter	Yes	Yes.
Lubricant cooler	Yes	Yes.
Thermostatic valve	Yes	Yes.
Electrical switchgear or frequency converter for the driver	Yes	Not applicable.[1]
Device to control the speed of the driver (e.g., variable speed drive)	Not applicable[2]	Yes.
Compressed air cooler(s)	Yes	Yes.
Pressure switch, pressure transducer, or similar pressure control device	Yes	Yes.
Moisture separator and drain	Yes	Yes.

[1]This category is not applicable to variable-speed rotary air compressors.

[2]This category is not applicable to fixed-speed rotary air compressors.

Table 2—Equipment Required During Test, if Distributed in Commerce With the Basic Model

Equipment	Fixed-speed rotary air compressors	Variable-speed rotary air compressors
Cooling fan(s) and motors	Yes	Yes.
Mechanical equipment	Yes	Yes.
Lubricant pump	Yes	Yes.
Interstage cooler	Yes	Yes.
Electronic or electrical controls and user interface	Yes	Yes.
All protective and safety devices	Yes	Yes.

B.5. The inlet of the compressor under test must be open to the atmosphere and take in ambient air for all tests specified in this appendix.

B.6. The compressor under test must be set up according to all manufacturer instructions for normal operation (*e.g.,* verify lubricant level, connect all loose electrical connections, close off bottom of unit to floor, cover forklift

holes).

B.7. The piping connected to the discharge orifice of the compressor must be of a diameter at least equal to that of the compressor discharge orifice to which it is connected. The piping must be straight with a length of at least 6 inches.

B.8. Transducers used to record compressor discharge pressure must be located on the discharge piping between 2 inches and 6 inches, inclusive, from the discharge orifice of the compressor. The pressure tap for transducers must be located at the highest point of the pipe's cross section.

II. Determination of Package Isentropic Efficiency, Package Specific Power, and Pressure Ratio at Full-Load Operating Pressure

A. Data Collection and Analysis

A.1. Stabilization. Record data at each load point under steady-state conditions. Steady-state conditions are achieved when a set of two consecutive readings taken at least 10 seconds apart and no more than 60 seconds apart are within the maximum permissible fluctuation from the average (of the two consecutive readings), as specified in Table 1 of ISO 1217:2009(E) (incorporated by reference, see §431.343) for—

(1) Discharge pressure;

(2) Temperature at the nozzle or orifice plate, measured per section 5.3 of ISO 1217:2009(E) (incorporated by reference, see §431.343); and

(3) Differential pressure over the nozzle or orifice plate, measured per section 5.2 of ISO 1217:2009(E) (incorporated by reference, see §431.343).

A.2. Data Sampling and Frequency. At each load point, record a minimum set of 16 unique readings, collected over a minimum time of 15 minutes. Each consecutive reading must be no more than 60 seconds apart, and not less than 10 seconds apart. All readings at each load point must be within the maximum permissible fluctuation from average specified in Table 1 of ISO 1217:2009(E) (incorporated by reference, see §431.343) for—

(1) Discharge pressure;

(2) Temperature at the nozzle or orifice plate, measured per section 5.3 of ISO 1217:2009(E) (incorporated by reference, see §431.343); and

(3) Differential pressure over the nozzle or orifice plate, measured per section 5.2 of ISO 1217:2009(E) (incorporated by reference, see §431.343).

If one or more readings do not meet the requirements, then all previous readings must be disregarded and a new set of at least 16 new unique readings must be collected over a minimum time of 15 minutes. Average the readings to determine the value of each parameter to be used in subsequent calculations.

A.3. Calculations and Rounding. Perform all calculations using raw measured values. Round the final result for package isentropic efficiency to the thousandth (*i.e.,* 0.001), for package specific power in kilowatts per 100 cubic feet per minute to the nearest hundredth (*i.e.,* 0.01), for pressure ratio at full-load operating pressure to the nearest tenth (*i.e.,* 0.1), for full-load actual volume flow rate in cubic feet per minute to the nearest tenth (*i.e.,*0.1), and for full-load operating pressure in pounds per square inch gauge (psig) to the nearest integer (*i.e.,* 1). All terms and quantities refer to values determined in accordance with the procedures set forth in this appendix for the tested unit.

B. Full-Load Operating Pressure and Full-Load Actual Volume Flow Rate

Determine the full-load operating pressure and full-load actual volume flow rate (referenced throughout this appendix) in accordance with the procedures prescribed in section III of this appendix.

C. Full-Load Package Isentropic Efficiency for Fixed- and Variable-Speed Air Compressors

Use this test method to test fixed-speed air compressors and variable-speed air compressors.

C.1. Test unit at full-load operating pressure and full-load volume flow rate according to the requirements established in sections I, II.A, and II.B of this appendix. Measure volume flow rate and calculate actual volume flow

rate in accordance with section C.4.2.1 of Annex C of ISO 1217:2009(E) (incorporated by reference, see §431.343) with no corrections made for shaft speed. Measure discharge gauge pressure and packaged compressor power input. Measured discharge gauge pressure and calculated actual volume flow rate must be within the deviation limits for discharge pressure and volume flow rate specified in Tables C.1 and C.2 of Annex C of ISO 1217:2009(E) (incorporated by reference, see §431.343), where full-load operating pressure and full-load actual volume flow rate (as determined in section III of this appendix) are the targeted values.

C.2. Calculate the package isentropic efficiency at full-load operating pressure and full-load actual volume flow rate (full-load package isentropic efficiency, $\eta_{isen,FL}$) using the equation for isentropic efficiency in section 3.6.1 of ISO 1217:2009(E) as modified by ISO 1217:2009/Amd.1:2016(E) (incorporated by reference, see §431.343). For P_{isen}, use the isentropic power required for compression at full-load operating pressure and full-load actual volume flow rate, as determined in section II.C.2.1 of this appendix. For P_{real}, use the real packaged compressor power input at full-load operating pressure and full-load actual volume flow rate, as determined in section II.C.2.2 of this appendix.

C.2.1. Calculate the isentropic power required for compression at full-load operating pressure and full-load actual volume flow rate using equation (H.6) of Annex H of ISO 1217:2009/Amd.1:2016(E) (incorporated by reference, see §431.343). For q_{V1}, use the actual volume flow rate (cubic meters per second) calculated in section II.C.1 of this appendix. For p_1, use 100 kPa. For p_2, use the sum of (a) 100 kPa, and (b) the measured discharge gauge pressure (Pa) from section II.C.1 of this appendix. For K, use the isentropic exponent (ratio of specific heats) of air, which, for the purposes of this test procedure, is 1.400.

C.2.2. Calculate real packaged compressor power input at full-load operating pressure and full-load actual volume flow rate using the following equation:

$$P_{real,100\%} = K_5 \cdot P_{PR,100\%}$$

Where:

K_5 = correction factor for inlet pressure, as determined in section C.4.3.2 of Annex C to ISO 1217:2009(E) (incorporated by reference, see §431.343). For calculations of this variable use a value of 100 kPa for contractual inlet pressure; and

$P_{PR,100\%}$ = packaged compressor power input reading at full-load operating pressure and full-load actual volume flow rate measured in section II.C.1 of this appendix (W).

D. Part-Load Package Isentropic Efficiency for Variable-Speed Air Compressors

Use this test method to test variable-speed air compressors.

D.1. Test unit at two load points: (1) Full-load operating pressure and 70 percent of full-load actual volume flow rate and (2) full-load operating pressure and 40 percent of full-load actual volume flow rate, according to the requirements established in sections I, II.A, and II.B of this appendix. To reach each specified load point, adjust the speed of the driver and the backpressure of the system. For each load point, measure volume flow rate and calculate actual volume flow rate in accordance with section C.4.2.1 of Annex C of ISO 1217:2009(E) (incorporated by reference, see §431.343), with no corrections made for shaft speed. For each load point, measure discharge gauge pressure and packaged compressor power input. Measured discharge gauge pressure and calculated actual volume flow rate must be within the deviation limits for discharge pressure and volume flow rate specified in Tables C.1 and C.2 of Annex C of ISO 1217:2009(E), where the targeted values are as specified in the beginning of this section.

D.2. For variable-speed compressors, calculate the part-load package isentropic efficiency using the following equation:

$$\eta_{isen,PL} = \omega_{40\%} \times \eta_{isen,40\%} + \omega_{70\%} \times \eta_{isen,70\%} + \omega_{100\%} \times \eta_{isen,100\%}$$

Where:

$\eta_{isen,PL}$ = part-load package isentropic efficiency for a variable-speed compressor;

$\eta_{isen,100\%}$ = package isentropic efficiency at full-load operating pressure and 100 percent of full-load actual volume flow rate, as determined in section II.C.2 of this appendix;

$\eta_{isen,70\%}$ = package isentropic efficiency at full-load operating pressure and 70 percent of full-load actual volume flow rate, as determined in section II.D.3 of this appendix;

$\eta_{isen,40\%}$ = package isentropic efficiency at full-load operating pressure and 40 percent of full-load actual volume flow rate, as determined in section II.D.4 of this appendix;

$\omega_{40\%}$ = weighting at 40 percent of full-load actual volume flow rate and is 0.25;

$\omega_{70\%}$ = weighting at 70 percent of full-load actual volume flow rate and is 0.50; and

$\omega_{100\%}$ = weighting at 100 percent of full-load actual volume flow rate and is 0.25.

D.3. Calculate package isentropic efficiency at full-load operating pressure and 70 percent of full-load actual volume flow rate using the equation for isentropic efficiency in section 3.6.1 of ISO 1217:2009(E) as modified by ISO 1217:2009/Amd.1:2016(E) (incorporated by reference, see §431.343). For P_{isen}, use the isentropic power required for compression at full-load operating pressure and 70 percent of full-load actual volume flow rate, as determined in section II.D.3.1 of this appendix. For P_{real}, use the real packaged compressor power input at full-load operating pressure and 70 percent of full-load actual volume flow rate, as determined in section II.D.3.2 of this appendix.

D.3.1. Calculate the isentropic power required for compression at full-load operating pressure and 70 percent of full-load actual volume flow rate using equation (H.6) of Annex H of ISO 1217:2009/Amd.1:2016(E) (incorporated by reference, see §431.343). For q_{V1}, use actual volume flow rate (cubic meters per second) at full-load operating pressure and 70 percent of full-load actual volume flow rate, as calculated in section II.D.1 of this appendix. For p_1, use 100 kPa. For p_2, use the sum of (a) 100 kPa, and (b) discharge gauge pressure (Pa) at full-load operating pressure and 70 percent of full-load actual volume flow rate, as calculated in section II.D.1 of this appendix. For *K,* use the isentropic exponent (ratio of specific heats) of air, which, for the purposes of this test procedure, is 1.400.

D.3.2. Calculate real packaged compressor power input at full-load operating pressure and 70 percent of full-load actual volume flow rate using the following equation:

$$P_{real,70\%} = K_5 \cdot P_{PR,70\%}$$

Where:

K_5 = correction factor for inlet pressure, as determined in section C.4.3.2 of Annex C to ISO 1217:2009(E) (incorporated by reference, see §431.343). For calculations of this variable use a value of 100 kPa for contractual inlet pressure; and

$P_{PR,70\%}$ = packaged compressor power input reading at full-load operating pressure and 70 percent of full-load actual volume flow rate, as measured in section II.D.1 of this appendix (W).

D.4. Calculate package isentropic efficiency at full-load operating pressure and 40 percent of full-load actual volume flow rate using the equation for isentropic efficiency in section 3.6.1 of ISO 1217:2009(E) as modified by ISO 1217:2009/Amd.1:2016(E) (incorporated by reference, see §431.343). For $P_{isen,}$ use the isentropic power required for compression at full-load operating pressure and 40 percent of full-load actual volume flow rate, as determined in section II.D.4.1 of this appendix. For $P_{real,}$ use the real packaged compressor power input at full-load operating pressure and 40 percent of full-load actual volume flow rate, as determined in section II.D.4.2 of this appendix.

D.4.1. Calculate the isentropic power required for compression at full-load operating pressure and 40 percent of full-load actual volume flow rate using equation (H.6) of Annex H of ISO 1217:2009/Amd.1:2016(E) (incorporated by reference, see §431.343). For q_{V1}, use actual volume flow rate (cubic meters per second) at full-load operating pressure and 40 percent of full-load actual volume flow rate, as calculated in section II.D.1 of this appendix. For p_1, use 100 kPa. For p_2, use the sum of (a) 100 kPa, and (b) discharge gauge pressure (Pa) at full-load operating pressure and 40 percent of full-load actual volume flow rate, as calculated in section II.D.1 of this appendix. For K, use the isentropic exponent (ratio of specific heats) of air, which, for the purposes of this test procedure, is 1.400.

D.4.2. Calculate real packaged compressor power input at full-load operating pressure and 40 percent of full-load actual volume flow rate using the following equation:

$$P_{real,40\%} = K_5 \cdot P_{PR,40\%}$$

Where:

K_5 = correction factor for inlet pressure, as determined in section C.4.3.2 of Annex C to ISO 1217:2009(E) (incorporated by reference, see §431.343). For calculations of this variable use a value of 100 kPa for contractual inlet pressure; and

$P_{PR,40\%}$ = packaged compressor power input reading at full-load operating pressure and 40 percent of full-load actual volume flow rate, as measured in section II.D.1 of this appendix (W).

E. Determination of Package Specific Power

For both fixed and variable-speed air compressors, determine the package specific power, at any load point, using the equation for specific energy consumption in section C.4.4 of Annex C of ISO 1217:2009(E) (incorporated by reference, see §431.343) and other values measured pursuant to this appendix, with no correction for shaft speed. Calculate P_{Pcorr} in section C.4.4 of Annex C of ISO 1217:2009(E) (incorporated by reference, see §431.343) using the following equation:

$$P_{Pcorr} = K_5 \cdot P_{PR}$$

Where:

K_5 = correction factor for inlet pressure, as determined in section C.4.3.2 of Annex C to ISO 1217:2009(E) (incorporated by reference, see §431.343). For calculations of this variable use a value of 100 kPa for contractual inlet pressure; and

P_{PR} = packaged compressor power input reading (W), as determined in section C.2.4 of Annex C to ISO 1217:2009(E) (incorporated by reference, see §431.343).

F. Determination of Pressure Ratio at Full-Load Operating Pressure

Pressure ratio at full-load operating pressure, as defined in §431.342, is calculated using the following equation:

$$LCL = \bar{x} - t_{0.95}\left(\frac{s}{\sqrt{n}}\right)$$

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Where:

PR = pressure ratio at full-load operating pressure;

p_1 = 100 kPa; and

p_{FL} = full-load operating pressure, determined in section III.C.4 of this appendix (Pa gauge).

III. Method to Determine Maximum Full-Flow Operating Pressure, Full-Load Operating Pressure, and Full-Load Actual Volume Flow Rate

A. Principal Strategy

The principal strategy of this method is to incrementally increase discharge pressure by 2 psig relative to a starting point, and identify the maximum full-flow operating pressure at which the compressor is capable of operating. The maximum discharge pressure achieved is the maximum full-flow operating pressure. The full-load operating pressure and full-load actual volume flow rate are determined based on the maximum full-flow operating pressure.

B. Pre-test Instructions

B.1. Safety

For the method presented in section III.C.1 of this appendix, only test discharge pressure within the safe operating range of the compressor, as specified by the manufacturer in the installation and operation manual shipped with the unit. Make no changes to safety limits or equipment. Do not violate any manufacturer-provided motor operational guidelines for normal use, including any restriction on instantaneous and continuous input power draw and output shaft power (*e.g.,* electrical rating and service factor limits).

B.2. Adjustment of Discharge Pressure

B.2.1. If the air compressor is not equipped, as distributed in commerce by the manufacturer, with any mechanism to adjust the maximum discharge pressure output limit, proceed to section III.B.3 of this appendix.

B.2.2. If the air compressor is equipped, as distributed in commerce by the manufacturer, with any mechanism to adjust the maximum discharge pressure output limit, then adjust this mechanism to the maximum pressure allowed, according to the manufacturer's operating instructions for these mechanisms. Mechanisms to adjust discharge pressure may include, but are not limited to, onboard digital or analog controls, and user-adjustable inlet valves.

B.3. Driver speed

If the unit under test is a variable-speed compressor, maintain maximum driver speed throughout the test. If the unit under test is a fixed-speed compressor with a multi-speed driver, maintain driver speed at the maximum speed throughout the test.

B.4. Measurements and Tolerances

B.4.1. Recording

Record data by electronic means such that the requirements of section B.4.5 of section III of this appendix are met.

B.4.2. Discharge Pressure

Measure discharge pressure in accordance with section 5.2 of ISO 1217:2009(E) (incorporated by reference, see §431.343). Express compressor discharge pressure in psig in reference to ambient conditions, and record it to the nearest integer. Specify targeted discharge pressure points in integer values only. The maximum allowable measured deviation from the targeted discharge pressure at each tested point is ±1 psig.

B.4.3. Actual Volume Flow Rate

Measure actual volume flow rate in accordance with section C.4.2.1 of Annex C of ISO 1217:2009(E) (incorporated by reference, see §431.343) (where it is called “corrected volume flow rate”) with no corrections made for shaft speed. Express compressor actual volume flow rate in cubic feet per minute at inlet conditions (cfm).

B.4.4. Stabilization

Record data at each tested load point under steady-state conditions, as determined in section II.A.1 of this appendix.

B.4.5. Data Sampling and Frequency

At each load point, record a set of at least of two readings, collected at a minimum of 10 seconds apart. All readings at each load point must be within the maximum permissible fluctuation from the average (of the two consecutive readings), as specified in II.A.2 of this appendix. Average the measurements to determine the value of each parameter to be used in subsequent calculations.

B.5. Adjusting System Backpressure

Set up the unit under test so that backpressure on the unit can be adjusted (*e.g.,* by valves) incrementally, causing the measured discharge pressure to change, until the compressor is in an unloaded condition.

B.6. Unloaded Condition

A unit is considered to be in an unloaded condition if capacity controls on the unit automatically reduce the actual volume flow rate from the compressor (*e.g.,* shutting the motor off, or unloading by adjusting valves).

C. Test Instructions

C.1. Adjust the backpressure of the system so the measured discharge pressure is 90 percent of the expected maximum full-flow operating pressure, rounded to the nearest integer, in psig. If the expected maximum full-flow operating pressure is not known, then adjust the backpressure of the system so that the measured discharge

pressure is 65 psig. Allow the unit to remain at this setting for 15 minutes to allow the unit to thermally stabilize. Then measure and record discharge pressure and actual volume flow rate at the starting pressure.

C.2. Adjust the backpressure of the system to increase the discharge pressure by 2 psig from the previous value, allow the unit to remain at this setting for a minimum of 2 minutes, and proceed to section III.C.3 of this appendix.

C.3. If the unit is now in an unloaded condition, end the test and proceed to section III.C.4 of this appendix. If the unit is not in an unloaded condition, measure discharge pressure and actual volume flow rate, and repeat section III.C.2 of this appendix.

C.4. Of the discharge pressures recorded under stabilized conditions in sections III.C.1 through III.C.3 of this appendix, identify the largest. This is the maximum full-flow operating pressure. Determine the full-load operating pressure as a self-declared value greater than or equal to the lesser of (A) 90 percent of the maximum full-flow operating pressure, or (B) 10 psig less than the maximum full-flow operating pressure.

C.5. The full-load actual volume flow rate is the actual volume flow rate measured at the full-load operating pressure. If the self-declared full-load operating pressure falls on a previously tested value of discharge pressure, then use the previously measured actual volume flow rate as the full-load actual volume flow rate. If the self-declared full-load operating pressure does not fall on a previously tested value of discharge pressure, then adjust the backpressure of the system to the self-declared full-load operating pressure and allow the unit to remain at this setting for a minimum of 2 minutes. The measured actual volume flow rate at this setting is the full-load actual volume flow rate.

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