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Displacement and dynamic compressors — Performance test code for electric driven low-pressure air compressor packages

Compresseurs volumétriques et turbocompresseurs — Code d'essai de performance des ensembles de compresseurs basse pression à entraînement électrique

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Contents

Page

Foreword

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This document was prepared by Technical Committee ISO/TC 118, *Compressors and pneumatic tools, machines and equipment*, Subcommittee SC 6 *Air compressors and compressed air systems*.

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Introduction

This document was developed in response to a recognized need to provide a methodology to correct performance of a low-pressure air compressor to guarantee conditions for positive displacement and dynamic compression types.

In dynamic compression, air is drawn between the blades on a rapid rotating compression impeller[1)] and accelerates to high velocity. The gas is then discharged through a diffuser, where the kinetic energy is transformed into static pressure. Dynamic low-pressure compressors are of a radial flow design, with the following typical examples:

— single-stage centrifugal (aka high speed “turbo”) compressors;

— multi-stage centrifugal compressors without intercooling.

Positive displacement low-pressure compressors work on the principle of trapping a volume of air and reducing its volume, internally or externally. Two basic types are typical, as follows:

— Rotary screw positive displacement compressor where air is drawn into a compression chamber formed by intermeshing rotors[1]. As the rotors turn, the cavity between the rotors becomes smaller, reducing the volume of the trapped air and increasing its pressure;

— Rotary lobe positive displacement compressor where air is drawn into the case and is trapped between the rotor and the case wall. These air pockets are progressively moved to the discharge port. At the discharge port, a back flow of air into the pocket from the higher-pressure discharge line produces a constant volume pressure rise.

Existing standards (e.g. ISO 1217, ISO 5389, ISO 18740) for positive displacement compressors and dynamic compressors, do not provide clear and concise means of comparing different technologies.

This document provides simplified wire to air performance test methods that measure true performance of low-pressure air compressor packages.

1) In this document the terms “rotor” and “impeller” are used to describe the rotating element(s) which cause(s) compression, and can be considered to be interchangeable.

Displacement and dynamic compressors — Performance test code for electric driven low-pressure air compressor packages

1 Scope

This document specifies the performance test method of electrically driven low-pressure air compressor packages, where the compression is performed by positive displacement or dynamic compression; utilising atmospheric air as the compression gas. Low-pressure air compressor packages are often referred to as "blowers".

NOTE Throughout this document, the term 'low-pressure compressor' is used to describe a low-pressure air compressor ("blower") package

Low-pressure compressors with and without means of controlling flow (control may be electrical (e.g. with a variable frequency drive) or mechanical or both) are covered.

This document applies to low-pressure compressors meeting all the following limits:

— Atmospheric inlet air pressure between 0,5 bar and 1,1 bar.

— Discharge vs inlet pressure differential between 0,1 bar and 2,5 bar.

— Discharge vs inlet pressure ratio between 1,1 and 3,5.

This document is not applicable to:

— positive displacement low-pressure compressors with a liquid in the compression element (such as liquid ring pumps and liquid injected low-pressure compressor of screw type)

— multi-stage low-pressure compressors other than multistage centrifugal compressors comprised of multiple, identical or very similar uncooled sections along a single shaft (repeating stages).

— single shaft, multistage centrifugal compressors are treated from the point of measurement and calculation as a single stage

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5167-1, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements*

ISO 9300, *Measurement of gas flow by means of critical flow nozzles*

ISO 17089-1, *Measurement of fluid flow in closed conduits — Ultrasonic meters for gas — Part 1: Meters for custody transfer and allocation measurement*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
acceptance test
performance test carried out in accordance with this document

Note 1 to entry: See Annex C for an example of acceptance test report.

3.2
displacement compressor
packaged compressor where a static pressure rise is obtained by allowing successive volumes of gas to be aspired into and exhausted out of a closed space by means of the displacement of a moving member

[SOURCE: ISO 5390:1977, 3.1]

3.3
dynamic compressor
packaged compressor in which the fluid pressure increase is obtained by transformation of kinetic energy into potential energy with continuous flow from intake point to discharge point

[SOURCE: ISO 5390:1977, 3.2]

3.4
external coolant
medium externally supplied to the compressor to which the generated heat is finally rejected

Note 1 to entry: This is usually ambient air or cooling water

[SOURCE: ISO 1217:2009, 3.1.7]

3.5
packaged compressor
compressor with prime mover, transmission, fully piped and wired internally, including ancillary and auxiliary items of equipment where these are within the scope of supply

[SOURCE: ISO 1217:2009, 3.1.13]

3.6
isentropic compression
idealized (i.e. reversible) adiabatic thermodynamic compression process that occurs without transfer of heat into or out of a system

3.7
rotational speed
number of revolutions of the compressor drive shaft per unit of time

[SOURCE: ISO 1217:2009, 3.1.18]

3.8
process air inlet point
point upstream of any technically required component

Note 1 to entry: In the case in which a technically required component is not physically present during the test the impact of the component on performance shall be accounted for

3.9
process air discharge point
point downstream of any technically required component

Note 1 to entry: In the case in which a technically required component is not physically present during the test the impact of the component on performance shall be accounted for

3.10
guarantee conditions
site conditions for which the equipment is expected to perform. Typically, this will include atmospheric pressure and ambient temperature

3.11
absolute pressure
pressure with reference to absolute zero, i.e. with reference to an absolute vacuum

Note 1 to entry: It equals the algebraic sum of atmospheric pressure and gauge pressure (static pressure or total pressure).

[SOURCE: ISO 3857-1:1977, 1.3, modified — The second sentence was moved as a note.]

3.12
ambient pressure
absolute pressure (3.11) of the atmospheric air measured in the vicinity of the compressor

[SOURCE: ISO 1217:2009, 3.2.2]

3.13
atmospheric pressure
absolute pressure (3.11) of the atmospheric air measured at the test place

[SOURCE: ISO 1217:2009, 3.2.3]

3.14
discharge pressure
total mean *absolute pressure* (3.11) at the *process air discharge point* (3.9)

3.15
inlet pressure
total mean *absolute pressure* (3.11) at the standard *process air inlet point* (3.8)

3.16
total pressure
pressure measured at the stagnation point when a gas stream is brought to rest and its kinetic energy is converted by an *isentropic compression* (3.6) from the flow condition to the stagnation condition

[SOURCE: ISO 1217:2009, 3.2.9]

3.17
ambient temperature
total temperature (3.20) of the atmospheric air in the vicinity of the compressor, but unaffected by it

[SOURCE: ISO 1217:2009, 3.3.1]

3.18
discharge temperature
total temperature (3.20) at the *process air discharge point* (3.9)

3.19
inlet temperature
total temperature (3.21) at the standard *process air inlet point* (3.8)

3.20
total temperature
temperature that would be measured at the stagnation point if a gas stream were brought to rest and its kinetic energy converted by an *isentropic compression* (3.6) from the flow condition to the stagnation condition

[SOURCE: ISO 1217:2009, 3.3.4]

3.21
relative humidity
ratio, in humid air, expressed as a percentage, of the water vapour actual pressure to the saturated vapour pressure at the same dry bulb temperature

$$\varphi = \frac{p}{p_{\text{sat}}}$$

where p is partial pressure (ISO 80000-4:2019, item 4-14.1) of vapour and p_{sat} is its partial pressure at saturation (at the same temperature)

[SOURCE: ISO 80000-5:2019, 5-33]

3.22
isentropic exponent
ratio of the specific heat at constant pressure to the specific heat at constant volume

3.23
actual volume flow rate
volume flow rate of air, compressed and delivered at the standard discharge point, referred to conditions of *total temperature* (3.20), total pressure and composition prevailing at the standard inlet point

3.24
isentropic power
power that is theoretically required to compress an ideal gas under constant entropy, from given inlet conditions to a given *discharge pressure* (3.14)

Note 1 to entry: The term "ideal gas" is used to indicate any gas in a condition or state so that it follows closely the ideal gas law

[SOURCE: ISO 1217:2009/Amd.1:2016, 3.5.1]

3.25
isentropic efficiency
ratio of the required *isentropic power* (3.24) to measured power for the same specified boundaries with the same gas and the same inlet conditions and *discharge pressure* (3.14)

$$\eta_{\text{isen}} = \frac{P_{\text{isen}}}{P_{\text{real}}}$$

[SOURCE: ISO 1217:2009/Amd.1:2016, 3.6.1]

3.26
power input
sum of the electrical power inputs to the prime mover and any ancillaries and auxiliaries driven from the compressor shaft or by a separate prime mover at rated supply conditions, including the effect of all equipment included in the *packaged compressor* (3.5)

Note 1 to entry: Auxiliaries include oil pump, cooling fan and integral compressed air dryer

Note 2 to entry: Rated supply conditions refer to phase, voltage, frequency and ampere capability

[SOURCE: ISO 1217:2009, 3.5.3]

3.27
specific energy requirement
<of a packaged compressor> *power input* (3.26) per unit of compressor actual volume flow rate

[SOURCE: ISO 1217:2009, 3.7.2]

3.28
specific isentropic compression work
work expressed as energy per unit mass of air during *isentropic compression* (3.6)

3.29
specific isochoric compression work
work expressed as energy per unit mass of air during isochoric compression

3.30
specific combined compression work
sum of the *specific isentropic compression work* (3.28) and *specific isochoric compression work* (3.29), weighted by the internal volume ratio

3.31
internal volume ratio
ratio of the enclosed volume at moment of closure of the inlet port to the enclosed volume at the moment of opening of the discharge port for a positive *displacement compressor* (3.2)

3.32
rotor tip speed
peripheral speed at the largest rotor/impeller tip diameter

3.33
machine Mach number
ratio of the rotor tip speed to the speed of sound of the fluid inlet state at inlet conditions

3.34
accounted for value
means (measured/estimated/calculated/corrected) – a simulated or calculated substitute characteristic of components not available for the test, for example; the pressure drop of a remote air filter

3.35
idle power consumption
total consumed power when the *packaged compressor* (3.5) is not producing flow to the discharge but is rotating at significant speed. i.e. for *packaged compressor* (3.5) equipped with idling functionality

3.36
standby power consumption
power required to keep the *packaged compressor* (3.5) ready for immediate start from non-rotating state

3.37
flow coefficient
flow velocity formed from the inlet volume flow and an impeller cross-section area and rendered dimensionless by the tip speed of the impeller

3.38
work coefficient
specific compression work of the reference process rendered dimensionless by the kinetic energy of tip speed

3.39
reduced speed
alternate test speed used to achieve ratio of Mach number for contract to test equal to one

3.40
two speed test
combination of one test to determine the thermodynamic performance and one test to determine the electromechanical performance

3.41
package motor
item(s) that is a part of the *packaged compressor* (3.5) including any additional drive train components

3.42
test motor
item(s) that replaces the *package motor* (3.41) for testing

3.43
shaft power
mechanical input power at the rotor/impeller

3.44
electromechanical
part of the total losses, total power consumption or total efficiency, that is not the result of the compression work on the gas

Note 1 to entry: This shall include the impact on said values from motor(s), control(s), gear(s), bearing(s), seal(s) and all auxiliaries (e.g. fans and pumps), whether said components are mounted on or related to the driver(s), compression element(s) or part of the package.

4 Units

General use of SI units (see ISO 80000-1) as given throughout this document is recommended, see Table 1 and Table 2. However, in agreement with accepted practice in the pneumatic industry sector, some non-preferred SI units, accepted by ISO, are also used, see

Table 1 — List of symbols

Symbol	Term	SI unit
c	sonic velocity	m/s
c_p	specific heat capacity	J/(kg·K)
D	the largest rotor/impeller tip diameter	m
e	specific energy	J/m^3
h	specific enthalpy	J/kg
Ma	machine Mach number	—
M	molar mass	kg/mol
m	mass	kg
q_m	mass flow	kg/s
n	rotational speed	1/s
P	power	W
p	pressure	Pa
R	specific gas constant	J/(kg·K)
Re	Reynolds number	—
s	specific entropy	J/(kg·K)
T	thermodynamic temperature	K
t	Celsius temperature	°C
U	supply voltage	V
u	tip speed	m/s

Table 1 *(continued)*

Symbol	Term	SI unit
v	specific volume	m^3/kg
v_i	internal volume ratio	—
V	volume	m^3
q_V	volume flow	m^3/s
X_n	ratio of reduced speeds of rotation	—
x	mass ratio of water vapour to dry gas	kg/kg
y	specific compression work	J/kg
Δ	difference	—
η	efficiency	—
ϑ	ratio of (RZ1 T1) values	—
κ	ratio of specific heat capacities (isentropic exponent)	—
π	pressure ratio	—
ρ	density	kg/m^3
ϕ	ratio of volume flow rate ratios	—
φ	flow coefficient	—
φ_{rel}	relative humidity	—
ψ	work coefficient	—
σ	standard deviation	—

Table 2 — List of subscripts used in this document

Subscript	Term
0	ambient
1	inlet (suction side)
2	discharge (discharge side)
air	dry air
abs	absolute (pressure)
amb	ambient (air, temperature)
co	corrected to guarantee conditions
cog	corrected to the pressure ratio and inlet volume flow of the guarantee point
comb	combined
cool	coolant
d	dynamic
em	electromechanical
dry	dry
g	guarantee conditions or performance data at guarantee conditions
i	internal or intermediate
isoc	isochoric
ideal	according to an ideal thermodynamic process
out	output
pack	Packaged compressor boundary
Pr	reference or standard process
red	reduced speed
ref	reference value
rel	relative

Table 2 *(continued)*

Subscript	Term
s	isentropic
sat	saturated
st	static
target	target
te	test result
te1	first test in 2-speed testing
te2	second test in 2-speed testing
tol	permissible deviation
tot	total
u	tip or peripheral
vap	vapour, vapor, steam
wet	moist
idle	idle
standby	standby

5 Guarantee and measurement

5.1 Packaged compressor

The packaged compressor shall comprise all components that are necessary for the long-term functioning of the low-pressure compressor under guarantee conditions and are needed to fulfil the object of the guarantee and the preconditions of the guarantee:

— low-pressure compressor with drive system;

— variable frequency drive (as applicable);

— cooling/lubrication system;

— inlet filter;

— inlet valve/guide vanes (as applicable);

— bearing power supply (as applicable);

— fully piped and wired internally;

— including ancillary and auxiliary items of equipment and all power devices that affect power consumption.

5.2 Preconditions of the guarantee

If no preconditions are defined in the contract, the preconditions of the guarantee shall be applied in accordance with Table 3 below.

For testing to be possible, at least the following shall be specified as the preconditions of the guarantee:

— air inlet pressure;

— air inlet temperature;

— air inlet humidity;

— coolant inlet temperature;