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Cycle energy requirement — Test method

Exigence d'énergie de cycle — Essais de réception

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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*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document was developed to provide guidance to determine the cycle energy requirement for all types of compressors. The types of compressors included in the consideration include dynamic and positive displacement designs. Applicable pressures include low pressure (e.g. blowers), typical air network pressures in industry and higher pressures needed for special application. Applications covered include but are not limited to standard industrial air production and gas compression for industrial and other purposes.

Compressors are used in almost all types of industries and in processes such as energy production and water treatment. In most industrial facilities, small and large, compressed air is an expected utility. In industry and elsewhere many processes demand gases to be compressed to certain pressures.

Compressing a gas is energy intensive and growing attention to the environmental impact has encouraged manufacturers of compressors to continuously raise the energy efficiency of its products.

The need for compressed gas usually varies with time. While some types of compressor can adapt to changes of demand by delivering variable amounts of gas all compressors will at some point change from gas delivery to no delivery and back. Such a no delivery mode, called idle mode, usually means the compressor is left running being ready to resume delivery on short notice while still consuming energy.

Until now performance data is typically given and evaluated for a steady state design point. It is also customary to provide data for the idle mode when the delivered amount of gas is zero. What is not provided at present time is the energy consumed in switching from idle mode to delivery and vice versa. Taken together the energy required for these two events combined can be referred to as the cycle energy requirement (CER).

Cycle energy requirement — Test method

1 Scope

This document applies to electrically driven positive displacement and dynamic compressors.

This document defines and describes the test method to evaluate the cycle energy requirement.

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*

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
standard inlet point
location at which gas enters the compressor package

3.2
standard discharge point
discharge point for a packaged compressor is the terminal outlet

3.3
inlet pressure
absolute pressure of the gas at the *standard inlet point* (3.1)

3.4
inlet temperature
total temperature at the *standard inlet point* (3.1) of the compressor

3.5
compressor package
compressor unit with prime mover, transmission, fully piped and wired and generally includes all ancillary items necessary for effective operation

3.6
compressor package power input
sum of the electrical power inputs to the prime mover and all other ancillary and auxiliary items included in the *compressor package* (3.5)

3.7
compressor package actual volume flow rate
actual volume flow rate of gas, compressed and delivered at the *standard discharge point* (3.2), referred to conditions of total temperature, total pressure and composition prevailing at the *standard inlet point* (3.1)

Note 1 to entry: Composition can refer to humidity, for instance.

3.8
thermal steady state
state in which the variation in the difference between inlet and outlet temperatures is within 1 K for a period of three minutes or more

3.9
idle power consumption
stable steady-state power consumption of the compressor at zero volume flow rate or at pressure ratio of one, the compressor shall always be able to reach this state independent of the number of load-idle cycles

Note 1 to entry: The idle power consumption can be zero.

3.10
rated discharge pressure
total pressure at the *standard discharge point* (3.2) where performance is measured.

3.11
offload discharge pressure
total pressure at the *standard discharge point* (3.2) when the *compressor package* (3.5) transitions to idle state

Note 1 to entry: The offload discharge pressure shall be between 100 % and 110 % of the rated discharge pressure.

3.12
minimum actual volume flow rate
lowest actual volume flow rate at which the compressor can run stable at the specified *offload discharge pressure* (3.10)

EXAMPLE For a centrifugal this can correspond to the surge anticipation limit at the offload discharge pressure. For a variable speed screw compressor this can correspond to the lowest speed point at the offload discharge pressure

3.13
measured power
power measured by a power meter at a specific time under specific conditions

3.14
ideal load-idle cycle
principle of operation where the transition from load to idle and idle to load is instantaneous at the *offload discharge pressure* (3.10) and minimum flow rate without consuming any additional energy

3.15
cycle energy requirement
CER
additional energy compared to what would be consumed during the *ideal load-idle cycle* (3.14) during switching of states at *offload discharge pressure* (3.10) and minimum flow rate

4 Symbols, abbreviations and subscripts

4.1 Symbols and abbreviations

Symbol/ abbreviation	Term	SI unit	Other practical units
CER	cycle energy requirement	J	MJ, kJ
p	pressure	Pa	MPa, bar, mbar
P	power	W	MW, kW
T	temperature	K	-°C
V	volume	m^3	l
q_V	volume flow rate	m^3/s	l/s, m^3/min, m^3/h
f	frequency	Hz	
t	time	s	min

4.2 Subscripts

Subscript	Term	Remark
i	Inlet	Inlet condition / ambient
d	Discharge	
1	compressor switches to the idle state	
2	zero-flow and steady state achieved	
3	compressor switches to the load state	
4	compressor is delivering flow downstream of non-return valve	
NRV	Non-return valve	
UNRV	Upstream of Non-Return Valve	
DNRV	Downstream of Non-Return Valve	
V	Volume	
L	Load	Machine running in load
min	Minimum	
L1	Rated	
L2	Offload	Maximum allowable working pressure
max	Maximum	
MEAS	Measured	
IDLE	Idle	Machine off-load, no compressed air delivered to customer
EST	Estimation	

5 Measuring equipment, methods and accuracy

5.1 General

The equipment and methods given in this document are not intended to restrict the use of other equipment and methods with the same or better accuracy.

All inspection, measuring, test equipment and devices that can affect the test shall be calibrated and adjusted at prescribed intervals, or prior to use, against certified equipment having a known valid relationship to nationally recognized standards.

5.2 Measurement of pressure and temperature

Pressure measurement shall have an accuracy of ±1 % at the measured value.

Temperature measurement shall have an accuracy of ±1 K.

The following characteristics shall be measured:

— package inlet pressure (at standard inlet point);

— package inlet temperature (at standard inlet point);

— package discharge pressure (at standard discharge point);

— pressure upstream of the non-return valve;

— pressure downstream of the non-return valve;

If the compressor package does not have an internal non-return valve, one can be installed downstream of the compressor package with the pressure measurement on both sides to allow for non-invasive measuring of cycle energy requirement.

5.3 Measurement of compressor package actual flow rate

The actual delivered flow rate of the compressor shall be measured by performing a test as indicated in both ISO 5167-1 and ISO 9300.

5.4 Measurement of compressor package power input

The compressor package power input measurement shall have an accuracy of ±1 % at the measured value.

5.5 Measurement logging frequency

The logging frequency of the pressure and power measurements shall be at least 10 Hz.

5.6 Throttle valve

An adjustable throttle valve is required downstream of the compressor package.

5.7 Non-return valve

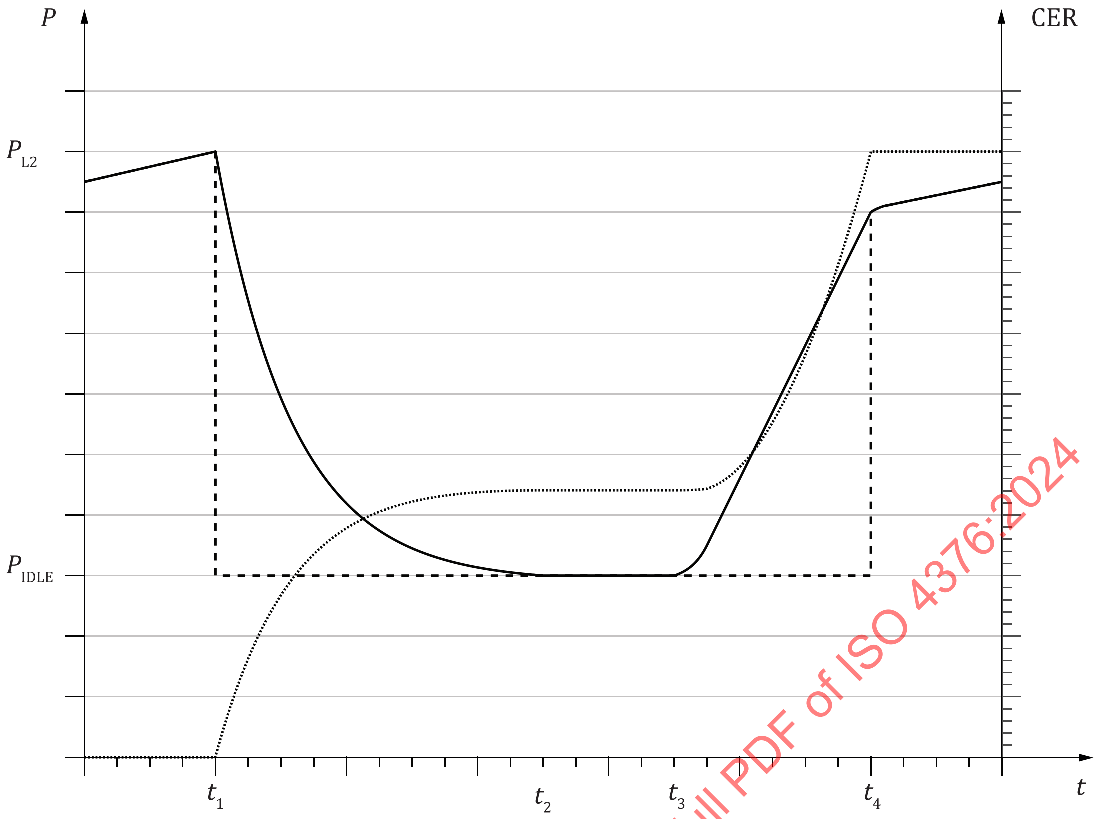
If a non-return valve (check valve) is not part of the compressor package, one shall be installed downstream for testing purposes.

6 Test procedure

Cycle energy requirement (CER) is the additional energy compared to what would be consumed during the ideal load-idle cycle during switching of states at offload discharge pressure and minimum flow rate, e.g., pressurizing the internals first when switching to load until the non-return valve is opened, e.g., venting the internals when switching to idle until an idle state is reached.

Figure 1 shows an example of the Cycle Energy Requirement compared to an ideal load-idle cycle where at time t_1 the compressor switches to idle and at time t_4 the product finally delivers air back to the customer at the requested pressure.

A full compressor package cycle includes a venting phase (t_1 to t_2), a steady state zero flow phase (t_2 to t_3) and a loading phase (t_3 to t_4)



Key

t	time (s)
t_1	compressor switches to the idle state
t_2	zero-flow and steady state achieved
t_3	compressor switches to the load state
t_4	compressor is delivering flow downstream of non-return valve
P	power (kW)
CER	cycle energy requirement (kJ)
———	typical load-idle cycle
-----	idealized load-idle cycle
....	cycle energy requirement

Figure 1 — Example cycle energy requirement

6.1 CER test conditions and limitations

The CER test conditions shall be as close as is reasonably possible to the conditions specified in Table 1 and not exceed the deviations given in Table 2.

Table 1 — Specified CER test conditions

Quantity	Unit	Value
Package inlet pressure	bara	1
Package inlet temperature	°C	20

Table 2 — CER test limitations

Quantity	Maximum deviations from specified values	Maximum permissible fluctuation from average during any set of readings
Package inlet pressure	±10 %	±1 %
Package inlet temperature	±10 K	±2 K

6.2 Cycle energy requirement test method

The compressor package shall be run under load to achieve thermal steady state before any measurements of minimum actual volume flow and package power input, idle power or cycle energy requirement.

Annex B describes the typical control strategies used on different compressor types.

6.2.1 (Optional) Full load actual volume flow and package power input

Compressor package shall be put in the rated discharge pressure and full load actual volume flow rate point. When thermal steady state is reached, the actual volume flow rate and package power input shall be measured and recorded.

6.2.2 Minimum actual volume flow and package power input

Compressor package shall be put in the offload discharge pressure and minimum actual volume flow rate point. When thermal steady state is reached, the actual volume flow rate and package power input shall be measured and recorded.

6.2.3 Idle power

Compressor package shall be placed in idle mode, allowed to stabilize and the total input power recorded, P_{IDLE}.

6.2.4 Logging data

A minimum of three (3) cycles shall be recorded and the result averaged. Package input power and necessary pressure readings to determine the cycle shall be recorded.

6.2.5 Cycling modes and determination of cycle

There are two alternative methods to run the compressor package through a single cycle:

a) Automatic; the discharge throttle valve position is adjusted to force the compressor package into cycling mode using on-board control system.

b) Manual; triggers can be used to switch the compressor from load to idle and vice versa.

6.2.5.1 Automatic mode

6.2.5.1.1 Preparation

Installation of an air receiver is highly recommended downstream of the compressor package and before the throttle valve. For suitable sizing of the air receiver, Formula (1) can be used:

$$V = \frac{0,25 \times q_V \times p_1 \times T_\mathrm{i}}{f_{\max} \times (p_{\mathrm{L}2} - p_{\mathrm{L}1}) \times T_\mathrm{d}} \tag{1}$$

6.2.5.1.2

Define and set pressure $p_{\mathrm{L}1}$ to the rated discharge pressure of the compressor.

Define and set pressure p_{L2} to the offload discharge pressure of the compressor.

6.2.5.1.3

Modify the throttle valve opening to force the compressor package into a successive Load condition.

The compressor should keep cycling continuously between load and idle.

6.2.5.1.4

t_1 records the state when the compressor switches to the idle state.

which corresponds to (p_{UNRV} < 99 % × p_{L1}) at minimum flow rate.

Between t_1 and t_2, the pressure downstream of the non-return valve shall not drop below p_{L1}.

6.2.5.1.5

t_2 records the state when the zero-flow power has reached steady state conditions, which corresponds to ($P_{MEAS} < P_{IDLE}$ + 1 % × P_{L2}).

During the test cycle, reaching t_2 shall be guaranteed.

6.2.5.1.6

The compressor package will automatically switch back to loaded state.

6.2.5.1.7

t_3 records the state when the compressor package switches to the loaded state, which corresponds to ($P_{MEAS} > P_{IDLE}$ + 1 % × P_{L2})

Between t_3 and t_4, the pressure downstream of the non-return valve shall not drop below $p_{L1.}$

6.2.5.1.8

t_4 records the state when the compressor is again in loaded state, which corresponds to (p_{UNRV} > 99 % × p_{L1}) and (P_{MEAS} > 90 % × $P_{q_V,min}$).

During the test cycle, reaching t_4 shall be guaranteed.

t_4 ends the single cycle measurement.

6.2.5.2 Manual mode

6.2.5.2.1 Preparation

The on-board compressor machine controls need to have triggers to force the compressor package into idle and load state.

6.2.5.2.2

Define and set pressure p_{L1} to the rated discharge pressure of the compressor.

Define and set pressure p_{L2} to the offload discharge pressure of the compressor.

6.2.5.2.3

Manually trigger on-board compressor machine controls to force the compressor package into idle state when in p_{L2} the offload discharge pressure and minimum flow rate.

6.2.5.2.4

t_1 records the state when the compressor switches to the idle state, which corresponds to

($p_{UNRV} < 99\ \% \times p_{L1}$) at minimum flow rate

Between t_1 and t_2, the pressure downstream of the non-return valve shall not drop below $p_{L1.}$

6.2.5.2.5

t_2 records the state when the zero-flow power has reached steady state conditions, which corresponds to ($P_{MEAS} < P_{IDLE} + 1\ \% \times P_{L2}$)

During the test cycle, reaching t_2 shall be guaranteed.

6.2.5.2.6

Manually trigger on-board compressor machine controls to force the compressor package into loaded state.

6.2.5.2.7

t_3 records the state when the compressor package switches to the loaded state, which corresponds to ($P_{MEAS} > P_{IDLE} + 1\ \% \times P_{L2}$)

Between t_3 and t_4, the pressure downstream of the non-return valve shall not drop below $p_{L1.}$

6.2.5.2.8

t_4 records the state when the compressor is again in loaded state, which corresponds to ($p_{UNRV} > 99\ \% \times p_{L1}$) and ($P_{MEAS} > 90\ \% \times\ P_{q_V,\min}$).

During the test cycle, reaching t_4 shall be guaranteed.

t_4 ends the single cycle measurement.

6.3 Calculation of cycle energy requirement

The following Formula (2) is used to calculate the cycle energy requirement. Using the power data recorded for the full cycle:

$$\text{CER} = \left(\int_{t_1}^{t_2} P_{\text{MEAS}}\, \mathrm{d}t + \int_{t_3}^{t_4} P_{\text{MEAS}}\, \mathrm{d}t - P_{\text{IDLE}} \times (t_4 - t_3 + t_2 - t_1) \right) \tag{2}$$

where:

- t_x is the time defined by the different changes in state and P_{MEAS} is the measured power consumption during the whole cycle.
- t_1 records the state when the compressor switches to the idle state
- t_2 records the state when the zero-flow power has reached steady state conditions
- t_3 records the state when the compressor package switches to the loaded state
- t_4 records the state when the compressor is again delivering flow and is running at full load operating pressure, p_{L1}

Formula (2) guarantees a correct cycle energy requirement measurement without taking into account the idle power, P_{IDLE}.

Annex A defines a simplified method to estimate the cycle energy requirement.

6.4 Test report

The test report shall be short, simple without calculations and with the essential corrections cited to guarantee a reproduceable and transparent result.

The test report shall contain:

— rated discharge pressure;

— offload discharge pressure;

— (optional) full load actual volume flow rate;

— (optional) full load package input power;

— minimum actual volume flow rate;

— package input power at minimum actual volume flow rate;

— idle power;

— inlet pressure;

— cycle energy requirement.

Annex A
(informative)

Cycle energy requirement — Simplified estimation

A.1 General

The CER test is a non-intrusive measurement procedure. This annex describes a calculation methodology which makes a cycle energy requirement estimation based on easy to capture parameters.

NOTE This methodology will always give higher cycle energy requirement than actual measurements.

A.2 Simplified estimation

The estimation is based on a simplified calculation given by Formula (3):

$$\mathrm{CER}_{\mathrm{EST}} = (t_4 - t_3 + t_2 - t_1) \times (P_{\mathrm{L2}} - P_{\mathrm{IDLE}}) \tag{3}$$

with t_1, t_2, t_3 and t_4 the different times defined in the cycle energy test procedure. P_{L2} the power consumption at the maximum allowable discharge pressure (unload set point) and P_{IDLE} the idle power consumption.

Annex B
(informative)

Cycle energy requirement — Compressor control strategies

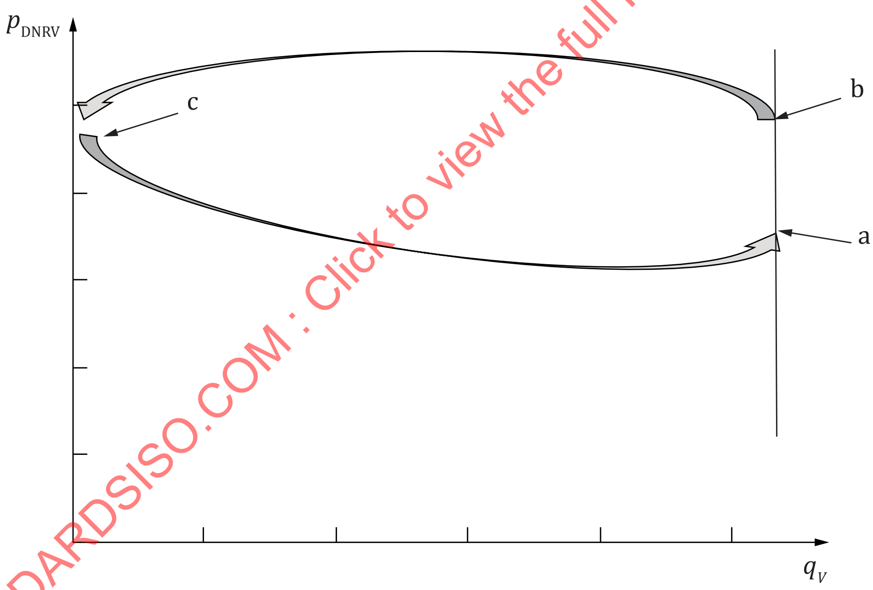
B.1 General

The CER acceptance test is a non-intrusive measurement procedure. This annex describes many of the typical compressor control strategies to give an informative insight to how a compressor reacts to flow changes.

B.2 Volumetric fixed speed compressor — Cycling regulation

A volumetric fixed speed compressor operating with cyclic regulation delivers a fixed volume downstream of the non-return valve. When volume delivered exceeds demand, the compressor switches to a zero-flow condition. As demand returns, the compressor will switch back to loaded state.

Figure B.1 represents the pressure downstream of the non-return valve and the cycle represented by unload (b), zero flow steady state (c) and returning to load state (a).



Key

q_V volume flow downstream of non-return valve

p_{DNRV} pressure downstream of non-return valve

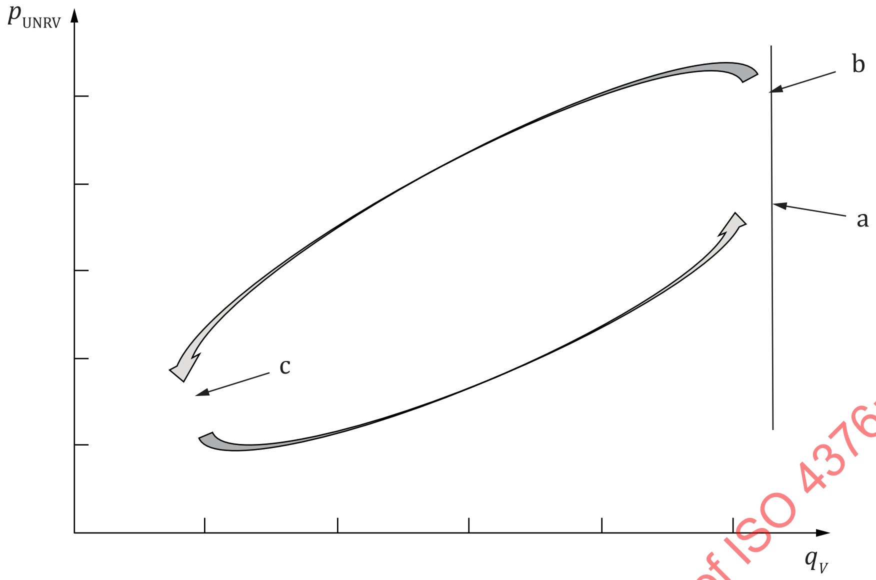
[a] Compressor is delivering flow downstream of non-return valve.

[b] Compressor switches to the idle state.

[c] Zero-flow and steady state achieved.

Figure B.1 — Volumetric fixed speed compressor — Cycling regulation

Figure B.2 represents the pressure before the non-return valve and the cycle represented by unload (b), the internal pressure reduction (c) at zero flow and return as demand resumes and internal pressure will increase to exceed pressure downstream of non-return valve (a).



Key

q_V volume flow upstream of non-return valve

p_{UNRV} pressure upstream of non-return valve

a Compressor is delivering flow downstream of non-return valve.

b Compressor switches to the idle state.

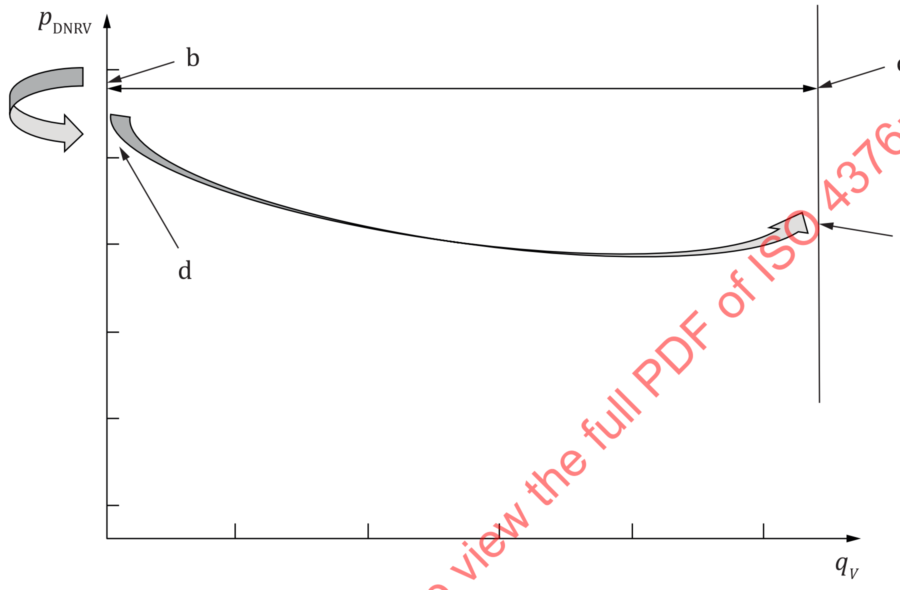
c Zero-flow and steady state achieved.

Figure B.2 — Volumetric fixed speed compressor — Cycling regulation

B.3 Volumetric fixed speed compressor — Blow-off regulation

A volumetric fixed speed compressor operating with blow-off regulation delivers a fixed volume downstream of the non-return valve. When volume delivered exceeds demand, the compressor opens a blow-off valve to vent excess capacity whilst still delivering some volume flow downstream of the non-return valve. When blow-off cannot sustain desired capacity demand, the compressor will switch to zero flow. Once demand returns, the compressor will switch back to loaded state.

Figure B.3 represents the cycle, blow-off starts when full volume flow rate exceeds demand (b). At the point when blow-off can no longer match capacity, the compressor will switch to zero flow state (c). Steady state is achieved (d) and with resumed demand the compressor changes to load (a). Cycle energy is measured from (c) through to (a).



Key

q_V volume flow downstream of non-return valve

p_{DNRV} pressure downstream of non-return valve

a Compressor is delivering flow downstream of non-return valve.

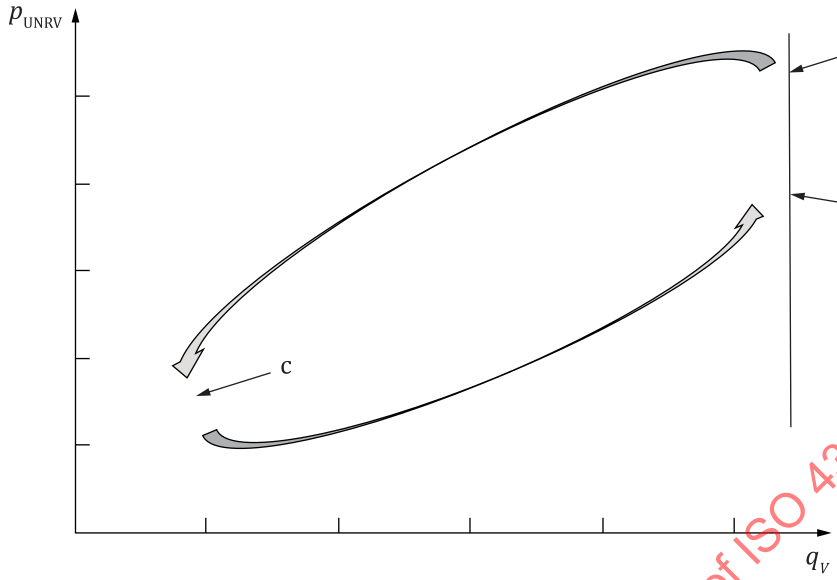
b Compressor switches to the idle state – excess capacity is vented.

c Compressor achieves zero-flow state.

d Zero-flow and steady state achieved.

Figure B.3 — Volumetric fixed speed compressor — Blow-off regulation

Figure B.4 represents the pressure before the non-return valve and the cycle represented by unload (b), the internal pressure reduction (c) at zero flow and return as demand resumes and internal pressure will increase to exceed pressure downstream of non-return valve (a).



Key

q_V volume flow upstream of non-return valve

p_{UNRV} pressure upstream of non-return valve

a Compressor is delivering flow downstream of non-return valve.

b Compressor switches to the idle state.

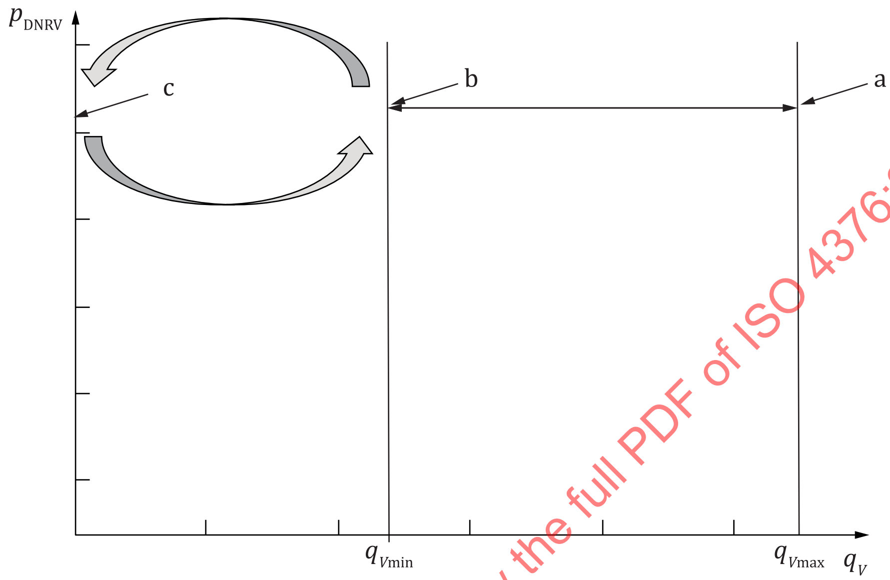
c Zero-flow and steady state achieved.

Figure B.4 — Volumetric fixed speed compressor — Blow-off regulation

B.4 Volumetric variable capacity compressor — Cycling regulation

A volumetric variable capacity compressor operating with cyclic regulation delivers a variable volume downstream of the non-return valve. When maximum possible volume flow rate delivered exceeds demand, the compressor reduces the capacity to match supply to demand. When minimum volume flow rate exceeds demand, the compressor switches to a zero-flow condition. As demand returns, the compressor will switch back to loaded state.

Figure B.5 represents the pressure downstream of the non-return valve and the cycle represented by unload at minimum capacity (b), zero flow steady state (c) and returning to load state (b).

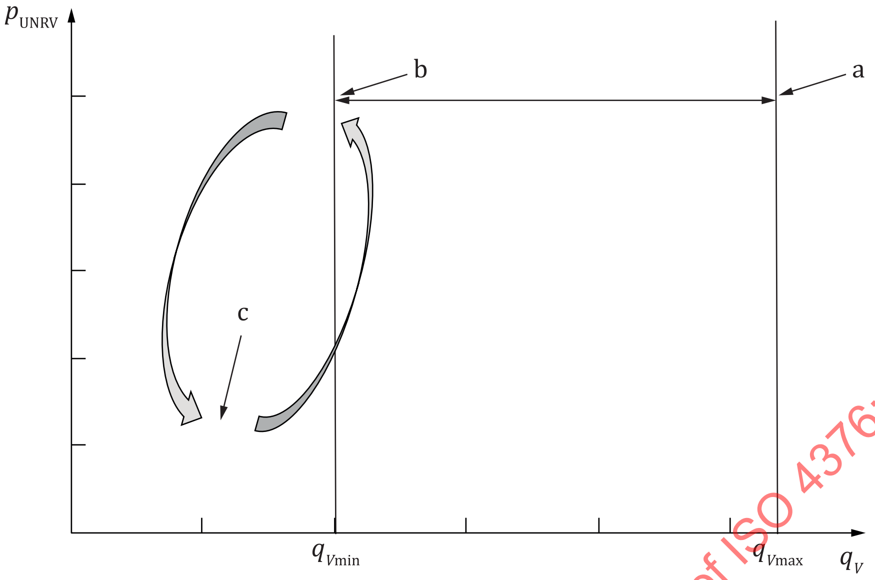


Key

q_V	flow downstream of non-return valve
p_{DNRV}	pressure downstream of non-return valve
q_{Vmin}	volume flow rate (minimum)
q_{Vmax}	volume flow rate (maximum)
[a]	Compressor is delivering flow downstream of non-return valve.
[b]	Compressor switches to the idle state.
[c]	Zero-flow and steady state achieved.

Figure B.5 — Volumetric variable capacity compressor — Cycling regulation

Figure B.6 represents the pressure before the non-return valve and the cycle represented by unload at minimum volume flow rate (b), the internal pressure reduction (c) at zero flow and return as demand resumes and internal pressure will increase to exceed pressure downstream of non-return valve (b).



Key

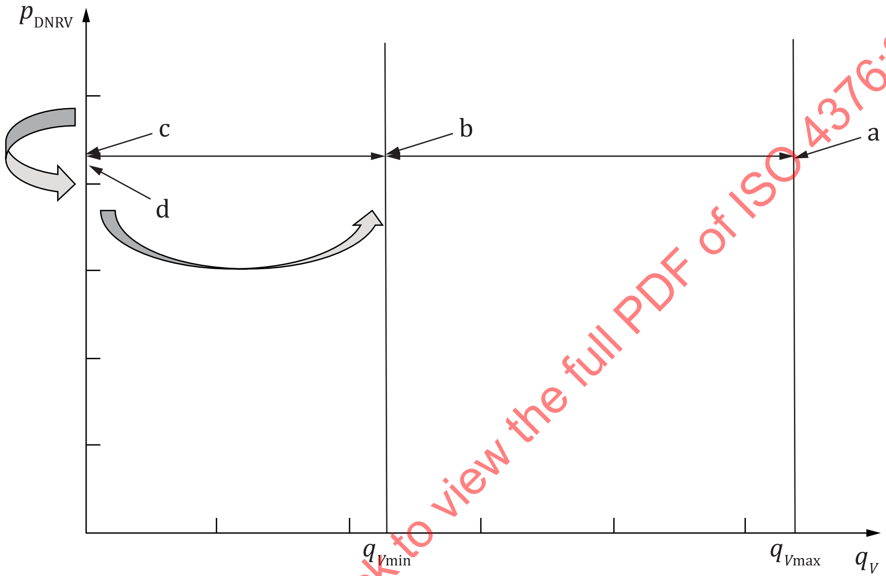
q_V	volume flow upstream of non-return valve
p_{UNRV}	pressure upstream of non-return valve
q_{Vmin}	volume flow rate (minimum)
q_{Vmax}	volume flow rate (maximum)
a	Compressor is delivering flow downstream of non-return valve.
b	Compressor switches to the idle state.
c	Zero-flow and steady state achieved.

Figure B.6 — Volumetric variable capacity compressor — Cycling regulation

B.5 Volumetric variable capacity compressor — Blow-off regulation

A volumetric capacity compressor operating with blow-off regulation delivers a variable volume flow downstream of the non-return valve. Volume flow modulated with capacity regulation and when minimum volume flow delivered still exceeds demand, the compressor opens a blow-off valve to vent excess capacity whilst still delivering some volume flow downstream of the non-return valve. If capacity delivered still exceeds demand, the compressor will switch to zero flow state. Once demand returns, the compressor will switch back to loaded state.

Figure B.7 represents the cycle, capacity regulation occurs as demand reduces. At the minimum flow (b), the compressor opens a blow-off valve to vent excess flow but still delivers some air to the network. If the flow at minimum speed and fully vented exceeds demand, the compressor will switch to a zero flow state. When demand resumes, compressor will return to a running state at minimum flow. Cycle energy represented from (c) through (d) to (b).

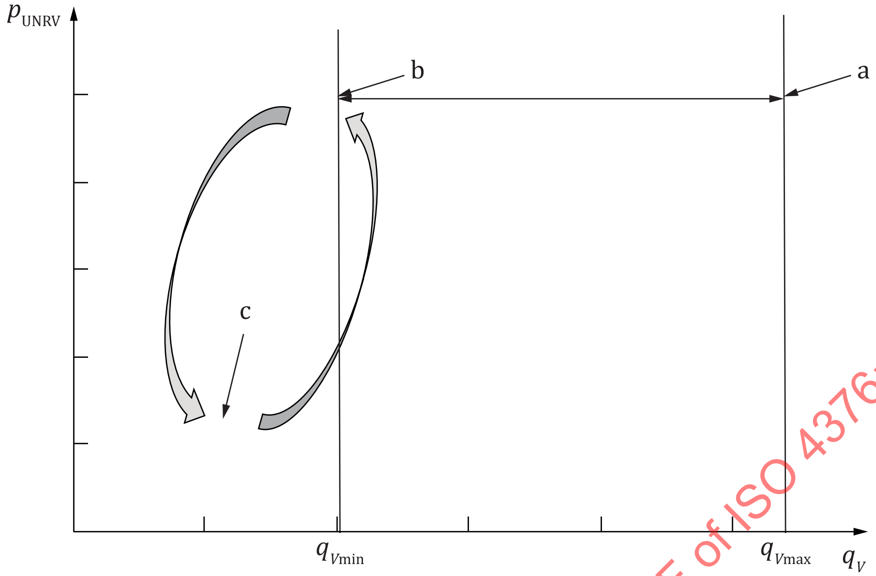


Key

q_V flow downstream of non-return valve
p_{DNRV} pressure downstream of non-return valve
q_{Vmin} volume flow rate (minimum)
q_{Vmax} volume flow rate (maximum)
a Compressor is delivering flow downstream of non-return valve.
b Compressor switches to the idle state – excess capacity vented.
c Compressor switches to the idle state.
d Zero-flow and steady state achieved.

Figure B.7 — Volumetric variable capacity compressor — Blow-off regulation

Figure B.8 represents the pressure before the non-return valve and the cycle represented by blow-off (b), the internal pressure drop (c) at zero flow and return as demand resumes and internal pressure will increase to exceed pressure downstream of non-return valve (b). Cycle energy is represented from (b) through (c) and back to point (b)



Key

q_V	volume flow upstream of non-return valve
p_{UNRV}	pressure upstream of non-return valve
$q_{V\min}$	volume flow rate (minimum)
$q_{V\max}$	volume flow rate (maximum)
a	Compressor is delivering flow downstream of non-return valve.
b	Compressor switches to the idle state.
c	Zero-flow and steady state achieved.

Figure B.8 — Volumetric variable capacity compressor — Blow-off regulation