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Third edition
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Hydraulic fluid power — Positive-displacement pumps, motors and integral transmissions — Methods of testing and presenting basic steady state performance

Transmissions hydrauliques — Pompes, moteurs et variateurs volumétriques — Méthodes d'essai et de présentation des données de base du fonctionnement en régime permanent

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 131, *Fluid power systems*, Subcommittee SC 8, *Product testing*.

This third edition cancels and replaces the second edition (ISO 4409:2007), which has been technically revised.

The main changes compared to the previous edition are as follows:

— The normative references in Clause 2 have been updated and revised to reflect the changes made to this document.

— The terms and definitions in Clause 3 were updated and correctly referenced to agree with the existing ISO standards.

— Clause 4 now correctly references the appropriate standard for symbols and units and the corresponding table has been revised to display symbols and units correctly.

— The general description of Clause 5 was revised to include various types of conduits. A table with recommendations for the test fluid to be used is now provided, and the circuit diagrams have been revised for technical accuracy.

— The suggested expression of results has been updated in Clause 6 to include meaningful values obtained from the data gathered with the tests.

— The Bibliography has been updated.

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

In hydraulic fluid power systems, power is transmitted and controlled through a liquid under pressure within an enclosed circuit. Pumps are components that convert rotary mechanical power into hydraulic fluid power. Motors are components that convert hydraulic fluid power into rotary mechanical power. Integral transmissions (hydraulic drive units) are a combination of one or more hydraulic pumps and motors and appropriate controls forming a component.

With very few exceptions, all hydraulic fluid power pumps and motors are of the positive-displacement type, i.e. they have internal sealing means that make them capable of maintaining a relatively constant ratio between rotational speed and fluid flow over wide pressure ranges. They generally use gears, vanes or pistons. Non-positive displacement components, such as centrifugal or turbine types, are seldom associated with hydraulic fluid power systems.

Pumps and motors are available either as “fixed-” or “variable-displacement” types. Fixed-displacement units have pre-selected internal geometries that maintain a relatively constant volume of liquid passing through the component per revolution of the component's shaft. Variable-displacement components have means for changing the internal geometries so that the volume of liquid passing through the component per revolution of the component's shaft can be changed.

This document is intended to unify testing methods for hydraulic fluid power positive displacement hydraulic pumps, motors and integral transmissions to enable the performance of the different components to be compared.

Hydraulic fluid power — Positive-displacement pumps, motors and integral transmissions — Methods of testing and presenting basic steady state performance

1 Scope

This document specifies methods for determining the performance and efficiency of hydraulic fluid power positive displacement pumps, motors and integral transmissions. It applies to components having continuously rotating shafts.

This document specifies the requirements for test installations, test procedures under steady-state conditions and the presentation of test results.

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 1219-1, *Fluid power systems and components — Graphic symbols and circuit diagrams — Part 1: Graphic symbols for conventional use and data-processing applications*

ISO 4391, *Hydraulic fluid power — Pumps, motors and integral transmissions — Parameter definitions and letter symbols*

ISO 5598, *Fluid power systems and components — Vocabulary*

ISO 9110-1, *Hydraulic fluid power — Measurement techniques — Part 1: General measurement principles*

ISO 9110-2, *Hydraulic fluid power — Measurement techniques — Part 2: Measurement of average steady-state pressure in a closed conduit*

ISO 11631, *Measurement of fluid flow — Methods of specifying flowmeter performance*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4391 and ISO 5598 apply.

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

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

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

4 Symbols and units

The symbols and subscripts listed in Table 1 are as specified in ISO 4391. Units as shown in Table 1 are in accordance with ISO 80000-1 and ISO 80000-4.

The letters and figures shall all be used as subscripts to the symbols listed in Table 1 are as specified in ISO 4391. The graphical symbols used in Figures 1, 2, 3 and 4 shall be used in accordance with ISO 1219-1.

Table 1 — Symbols and units

Description	Symbol	Unit
Volume flow rate	q_V	$m^3\ s^{-1}$
Derived capacity	V_i	$m^3\ r^{-1}$
Rotational frequency	n	s^{-1}
Torque	T	N·m
Pressure	p	Pa[a]
Power	P	W
Mass density	ρ	$kg\ m^{-3}$
Isothermal bulk modulus secant	K_T	Pa[a]
Kinematic viscosity	ν	$m^2\ s^{-1}$[b]
Temperature	θ	K
Volume coefficient of thermal expansion	α	K^{-1}
Overall efficiency [c]	η_τ	—
Volumetric efficiency	η_ς	—
Rotational frequency ratio	Z	—

[a] 1 Pa = 1 N/m².

[b] 1 cSt = 1 $mm^2\ s^{-1}$.

[c] Efficiency may also be stated as a percentage.

NOTE When there is no risk of ambiguity (i.e. when a test has been carried out on a pump or a motor), the superscripts “P,” “M” and “T” specifying that the quantity concerns, respectively, a pump, a motor or an integral transmission, can be omitted.

5 Tests

5.1 Requirements

5.1.1 General

Installations shall be designed to prevent air entrainment during operation and measures shall be taken to remove all free air from the system before testing.

The unit under test shall be installed and operated in the test circuit in accordance with the manufacturer's instructions; see also Annex B.

The ambient temperature of the test area shall be recorded.

A filter shall be installed in the test circuit to provide the fluid-cleanliness level specified by the manufacturer of the unit under test. The position, number and specific description of each filter used in the test circuit shall be recorded.

Where pressure measurements are made within the piping, the requirements of ISO 9110-1 and ISO 9110-2 shall be met.

Where flow measurements are made, the requirements of ISO 11631 shall be met.

Where temperature measurements are made within the piping, the temperature tapping point shall be positioned between two and four times the internal diameter of the piping from the pressure-tapping point furthest away from the component.

Figures 1, 2, 3 and 4 illustrate basic circuits that do not incorporate all the safety devices necessary to protect against damage in the event of any component fracture or fragmentation. It is important that those responsible for carrying out the test give due consideration to safeguarding both personnel and equipment.

NOTE A "run in" procedure before testing can have a positive effect on the test results.

5.1.2 Installation of the unit under test

The unit to be tested in the circuit shall be in accordance with the applicable Figure 1, 2, 3 or 4.

5.1.3 Test fluids

The properties of hydraulic fluids affect pump and motor performance. Any fluid can be used for the test, if agreed between the parties concerned, but its characteristics shall be clearly defined, according to the properties listed in Table 2. In order to compare two components, the same fluid shall be used.

Table 2 — Test fluid specification

Property	Standard	Recommended	
Viscosity grade	ISO 3448	ISO VG 32	ISO VG 46
Fluid classification	ISO 6743-4	HM	
Fluid specification	ISO 11158	(Table 3, ISO 11158)	
Additional constraints			
Density, g/cc	ISO 3675	860 to 880	
Viscosity index	ISO 2909	95 to 115	
Viscosity modification	N/A	The use of additional viscosity modifiers is prohibited.	
Friction modification	N/A	The use of additional friction modifiers is prohibited.	

5.1.4 Temperatures

5.1.4.1 Controlled temperature

Tests shall be carried out at a stated test fluid temperature. The test-fluid temperature shall be measured at the inlet port of the unit under test and be within the range recommended by the manufacturer. It is recommended that measurements are made at two temperature levels, 50 °C and 80 °C.

The test fluid temperature shall be maintained within the limits stated in Table 3.

Table 3 — Indicated test fluid temperature tolerance

Measurement accuracy class (see Annex A)	A	B	C
Temperature tolerance (°C)	±1,0	±2,0	±4,0

5.1.4.2 Other temperatures

The fluid temperature may be measured at the following locations:

a) at the outlet port of the unit under test;

b) at the flow measurement point in the test circuit;

c) in the drainage fluid line (if applicable).

For an integral transmission, it might not be possible to measure all the temperatures required. Temperatures not recorded shall be noted in the test report.

5.1.5 Casing pressure

If the fluid pressure within the casing of the component under test can affect its performance, the fluid-pressure value in the case shall be maintained and shall be recorded.

5.1.6 Steady-state conditions

Each set of readings taken for a controlled value of a selected parameter shall be recorded only where the indicated value of the controlled parameter is within the limits shown in Table 4. If multiple readings of a variable are recorded the mean values shall be documented while the controlled parameter is within the operating limits. The maximum suggested time period to acquire each reading is 10 s at a minimum data acquisition rate of 1 000 Hz. Such readings should include zero displacement and idle operating conditions.

Test parameters are considered stabilized when they are within Table 4 limits.

Table 4 — Permissible variation of mean indicated values of controlled parameters

Parameter	Permissible variation for classes of measurement accuracy[a] (see Annex A)		
	A	B	C
Rotational frequency, %	±0,5	±1,0	±2,0
Torque, %	±0,5	±1,0	±2,0
Volume flow rate, %	±0,5	±1,5	±2,5
Pressure, Pa ($p_e < 2 \times 10^5$ Pa)[b]	$\pm 1 \times 10^3$	$\pm 3 \times 10^3$	$\pm 5 \times 10^3$
Pressure, % ($p_e \geqq 2 \times 10^5$ Pa)	±0,5	±1,5	±2,5

a The permissible variations listed in this table concern deviation of the indicated instrument reading and do not refer to limits of error of the instrument reading; see Annex A. These variations are used as an indicator of steady state and are also used where graphical results are presented for a parameter of fixed value. The actual indicated value should be used in any subsequent calculation of power, efficiency or power losses.

b 1 Pa = 1 N/m^2.

5.1.7 Pump inlet pressure

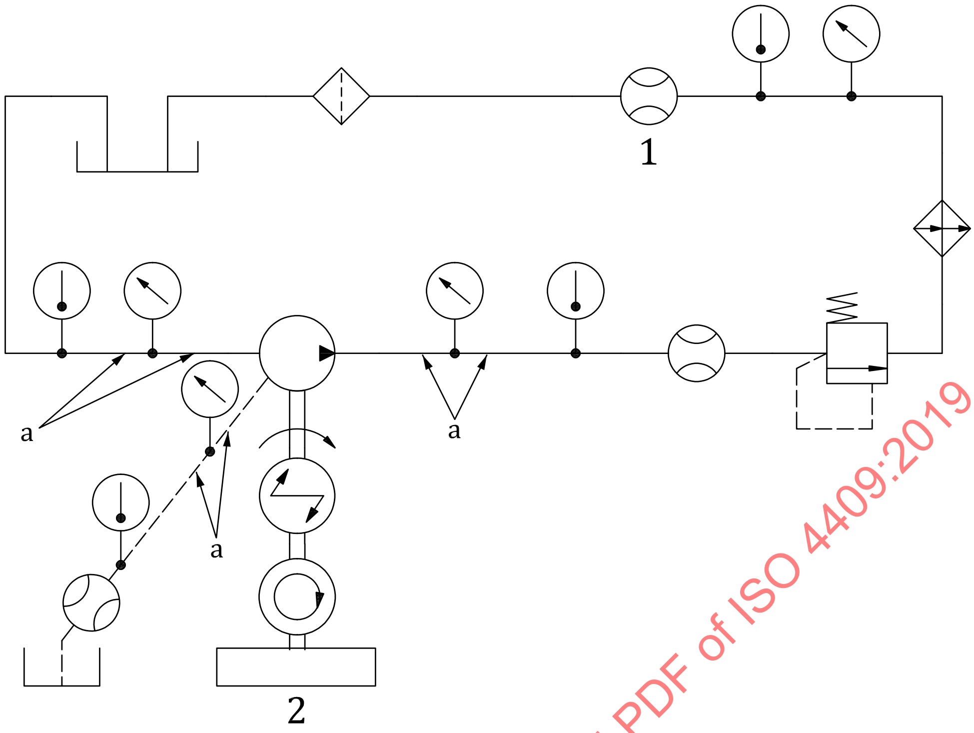
The pump inlet line should not exceed 25 000 Pa (0,25 bar or 3,6 psi). Unless otherwise required, the pump inlet pressure at the inlet fitting shall be maintained within 3 386 Pa (0,034 bar or 0,49 psi) of atmospheric pressure at pump maximum displacement and rated speed. This can be controlled by reservoir fluid level and/or reservoir pressure. The inlet pressure will be permitted to rise as variable pump displacement is reduced. A shutoff valve may be installed at least 20 internal diameters upstream from the pump in the inlet line.

5.2 Pump tests

5.2.1 Test circuits

5.2.1.1 Open-circuit tests

A test circuit configured in accordance with and containing at least the components shown in Figure 1 shall be used. Where a pressurized inlet condition is required, a suitable means shall be provided to maintain the inlet pressure within the specified limits (see 5.2.2). If an alternative position for the flow sensor is used, use pressure p and temperature θ measured at point 1 to calculate using the corresponding formula and symbols listed in ISO 4391:1983, Reference 10.18. Flow, pressure and temperature measured in drainage are not used in the formula.



Key

1 alternative position

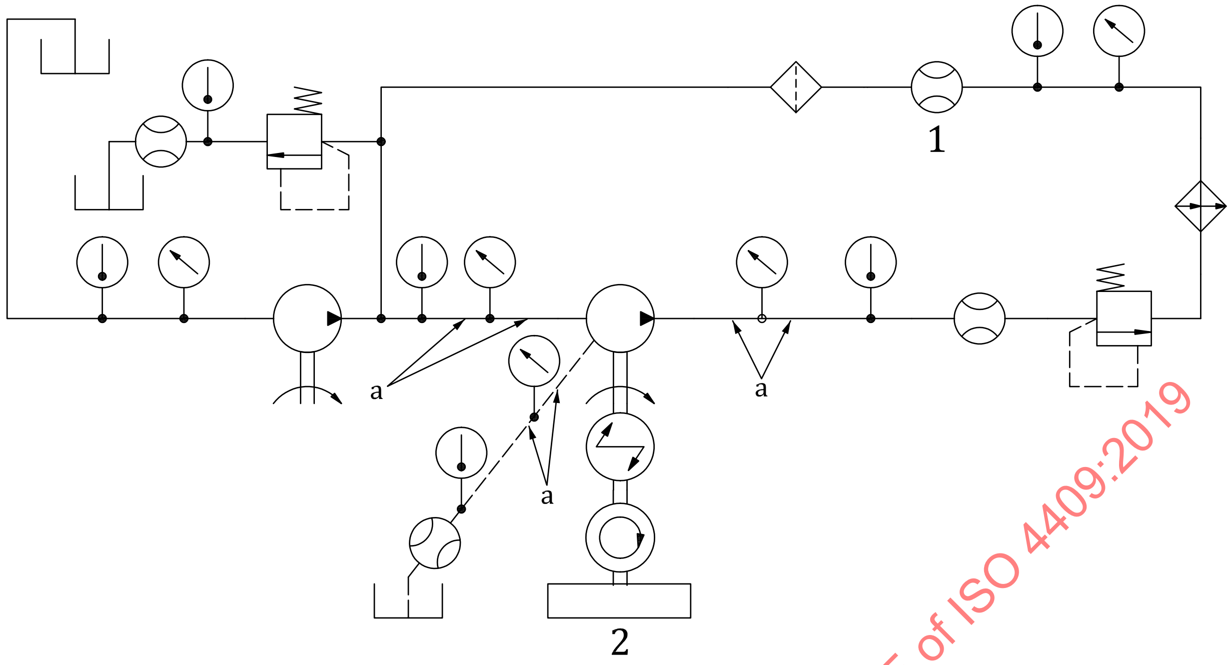
2 driver

a For pipe lengths see 5.1.1.

Figure 1 — Test circuit for pump unit (open circuit)

5.2.1.2 Closed-circuit tests

A test circuit configured in accordance with and containing at least the components shown in Figure 2 shall be used. In this circuit, the boost pump provides a flow slightly in excess of the total circuit losses. A greater flow may be provided for cooling purposes. If an alternative position for the flow sensor is used, use pressure p and temperature θ measured at point 1 to calculate using the corresponding formula in ISO 4391:1983, Ref.10.18. Flow, pressure and temperature measured in drainage are not used in the formula.



Key

1 alternative position

2 driver

[a] For pipe lengths see 5.1.1.

Figure 2 — Test circuit for pump unit (closed circuit)

5.2.2 Inlet pressure

During each test, maintain the inlet pressure constant (see Table 4) at a stated value within the permissible range of inlet pressures specified by the manufacturer. If required, carry out the tests at different inlet pressures.

5.2.3 Test measurements

Record measurements of

a) input torque;

b) outlet flow rate;

c) drainage flow rate (where applicable);

d) fluid temperature.

Test at a constant rotational frequency (see Table 4) and at a number of outlet pressures so as to give a representative indication of the pump performance over the full range of outlet pressures.

Repeat measurements 5.2.3 a) to d) at other rotational frequencies to give a representative indication of the pump performance over the full range of rotational frequencies.

5.2.4 Variable capacity

If the pump is of the variable capacity type, carry out complete tests at its maximum capacity setting and any other settings as required (e.g. 75 %, 50 % and 25 % of the maximum capacity setting). For variable displacement units, this test requires monitoring and recording the position of the displacement actuator to ensure it does not change during testing. If a swash plate type unit is used, the swivel angle shall be recorded by use of the position measurement from the displacement actuator. The swivel angle may be recorded instead of the position measurement from the displacement actuator.

Each of these settings shall give the required percentage of the flow rate at the minimum outlet pressure at the minimum rotational frequency specified for the test.

5.2.5 Reverse flow

If the direction of flow through the pump can be reversed (e.g. by means of a capacity control), carry out tests in both directions of flow.

5.2.6 Non-integral boost pumps

If the pump under test is associated with a separate boost pump and the power inputs can be measured separately, the pumps shall be tested and the results presented independently.

5.2.7 Full-flow, integral boost pump

If the boost pump is integral with the pump under test, which results in the power inputs being inseparable, and the boost pump contributes to the full flow of the main pump, the two pumps shall be treated as one integral unit and the results presented accordingly.

NOTE The inlet pressure being measured is boost pump inlet pressure.

Any excess flow from an external boost pump shall be measured and recorded.

5.2.8 Secondary-flow, integral boost pump

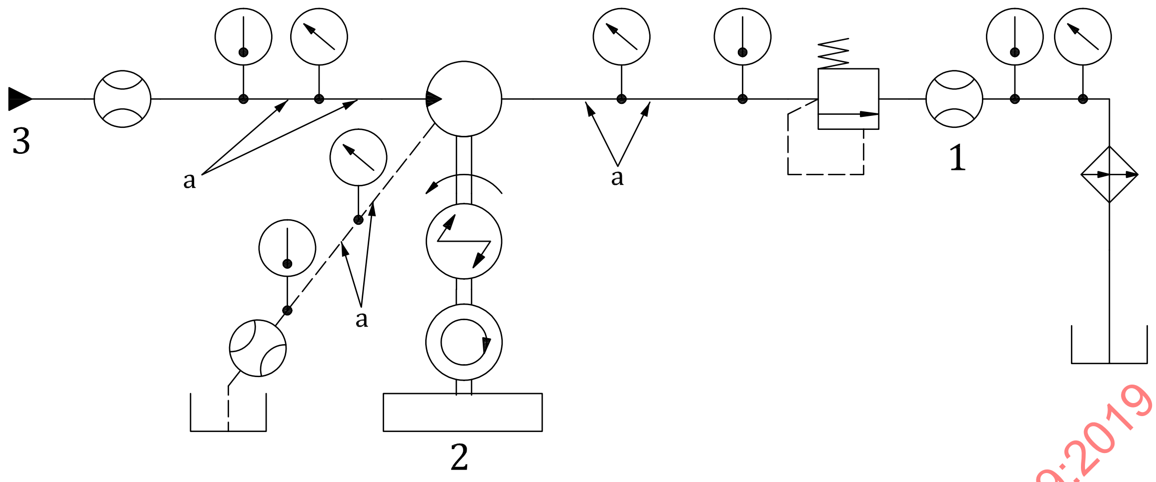
If the boost pump is integral with the main pump, which results in the power inputs being inseparable, but the boost pump supplies only a secondary flow to the hydraulic circuit of the main pump and the remainder is by-passed or used for an auxiliary service (e.g. cooling circulation), then, where practicable, in order to evaluate the boost pump volumetric efficiency, the flows from the boost pump shall be measured and recorded.

5.3 Motor tests

5.3.1 Test circuit

A test circuit configured in accordance with and containing at least the components shown in Figure 3 shall be used.

The flow rate should be measured with the standard position of the flow sensor indicated in Figure 3 for inlet flow at high pressure. If an alternative position for the flow sensor is used, use pressure p and temperature θ measured at point 1 to calculate using the corresponding formula and symbols listed in ISO 4391:1983, Reference 10.18. To calculate q_v, drainage flow should be measured. Pressure and temperature in drainage line are used to calculate flow in drainage line using the expression found in the same formula.



Key

1 alternative position

2 load

3 controlled fluid supply

a For pipe lengths see 5.1.1.

Figure 3 — Test circuit for motor unit

5.3.2 Outlet pressure

The outlet pressure from the motor shall be controlled (e.g. using a pressure control valve) so that a constant outlet pressure is maintained throughout the test, within the limits given in Table 4.

This outlet pressure shall meet the requirements of the envisaged motor application and the manufacturer's recommendations.

5.3.3 Test measurements

Measurements shall be taken of

a) inlet flow rate;

b) drainage flow rate (where applicable);

c) output torque;

d) test fluid temperature.

Test over the full rotational frequency range of the motor and at a number of different input pressures so as to give a representative indication of the motor performance over the full range of input pressures.

5.3.4 Variable capacity

If the motor is of the variable-capacity type, carry out complete tests at its minimum and maximum capacity settings and such other settings, as required (e.g. 75 %, 50 % and 25 % of the maximum capacity setting).

Obtain the percentage capacity by setting the adjustment to give the required proportional rotational frequency for the same inlet flow rate with zero output torque. The flow rate shall be chosen so that at minimum capacity the motor runs at its maximum rotational frequency.

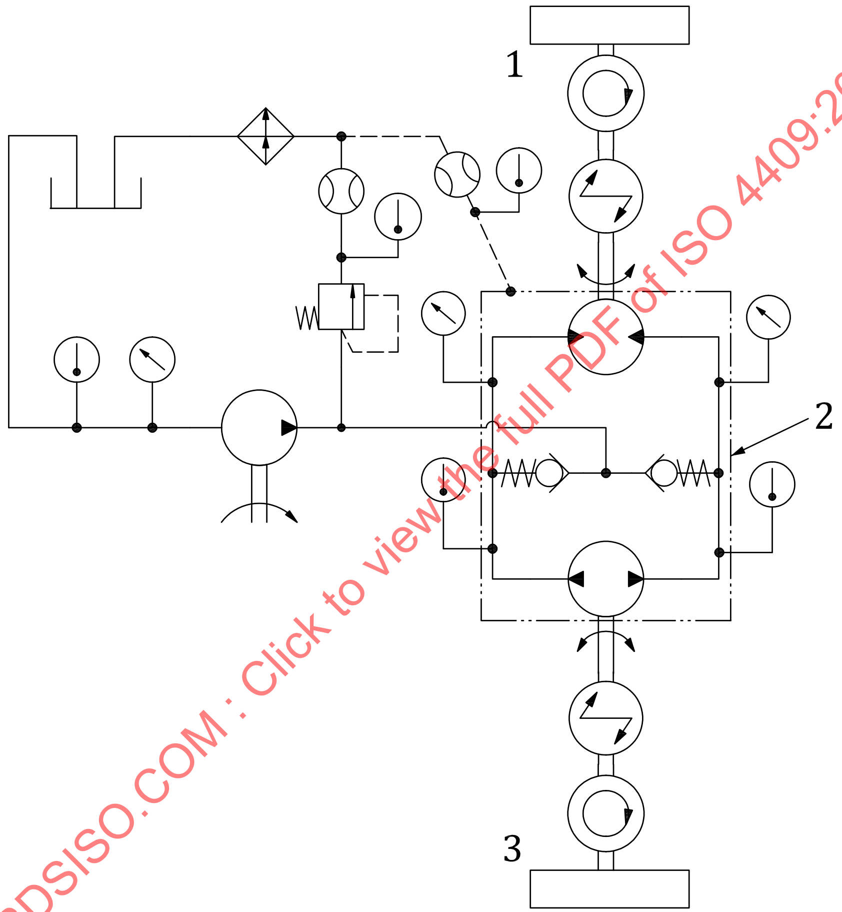
5.3.5 Reverse rotation

For motors that are required to operate in both directions of rotation, carry out tests in both directions.

5.4 Integral transmission tests

5.4.1 Test circuit

A test circuit configured in accordance with and containing at least the components shown in Figure 4 shall be used.



Key

1 load

2 integral transmission case

3 driver

Figure 4 — Integral transmission test circuit

5.4.2 Test measurements

The following test measurements shall be made with the integral transmission running at its maximum flow rate capacity for a specified input rotational frequency:

a) input torque;

b) output torque;

c) output rotational frequency;

d) test fluid pressure;

e) test fluid temperature, where appropriate.

Test over a power range as recommended by the manufacturer for a specified input rotational frequency.

Repeat the measurements given in 5.4.2 a) to e) for several different input rotational frequencies within the limits specified in Table 4.

If the pump unit is of the variable-capacity type, repeat the measurements given in 5.4.2 a) to e) at flow rates equal to 75 %, 50 % and 25 % of the pump maximum flow rate capacity, with the motor set at its maximum flow rate capacity.

The pump flow-rate capacity shall be determined as the ratio of the output shaft frequency at reduced pump flow-rate capacity to the output shaft frequency at maximum pump flow rate capacity, with no load applied to the output shaft and with the motor set at its maximum flow rate capacity.

If the motor unit is of the variable-capacity type, repeat the measurements given in 5.4.2 a) to e) with the motor set at its minimum flow rate capacity.

5.4.3 Boost pumps

If boost pumps or other auxiliaries are integral with the transmission pump and driven by the same input shaft, the pumps shall be treated as one integral unit and this information shall be recorded in the test results.

If boost pumps or other auxiliaries are driven separately, their power requirements shall be excluded from the transmission performance and this information shall be recorded in the test results.

5.4.4 Reverse rotation

If the output shaft is required to operate in both directions of rotation, tests shall be performed in both directions.

6 Expression of results

6.1 General

All test measurements and the calculation results derived from them shall be tabulated by the testing agency and presented graphically.

6.2 Pump tests

6.2.1 Pumps tested at one constant, rotational frequency

For a pump tested at one constant rotational frequency, graphs shall be plotted of the effective outlet pressure ($p_{2,e}$) versus

a) volumetric efficiency,

b) overall efficiency,

c) effective outlet flow rate, and

d) effective inlet mechanical power.

In addition, the parameters in Table 5 shall be recorded:

Table 5 — Parameters for pump testing at one constant, rotational frequency

Parameter	Result	Units
Test fluid used		—
Temperature of the test fluid at the pump inlet		K
Ambient temperature		K
Kinematic viscosity of the test fluid used at test temperature		$m^2 s^{-1}$
Density of the test fluid		$kg m^{-3}$
Effective pump inlet pressure		Pa
Percentage of pump full capacity at which the test was conducted		%
Rotational frequency of the pump at which the test was conducted		s^{-1}

An example of graphs for pump performance against effective outlet pressure is given in Figure C.1.

6.2.2 Pumps tested at several different, constant rotational frequencies

For a pump tested at a number of constant rotational frequencies, the results for each different effective outlet pressure value, $p_{2,e}$, used in the test shall be presented as described in 6.2.1 or graphs shall be plotted of the rotational frequency, n, versus

a) volumetric efficiency;

b) overall efficiency;

c) effective outlet flow rate; and

d) effective inlet mechanical power.

In addition, the parameters in Table 6 shall be recorded:

Table 6 — Parameters for pump testing at several different, constant rotational frequencies

Parameter	Result	Units
Test fluid used		—
Temperature of the test fluid at the pump inlet		K
Ambient temperature		K
Kinematic viscosity of the test fluid used at test temperature		$m^2 s^{-1}$
Density of the test fluid		$kg m^{-3}$
Effective pump inlet pressure		Pa
Percentage of pump full capacity at which the test was conducted		%
Effective pump outlet pressure		Pa

An example of graphs for pump performance against rotational frequency is given in Figure C.2.

6.3 Motor tests

For motors, graphs shall be plotted of the rotational frequency, n, versus the following for each different effective inlet pressure value, $p_{1,e}$, used in the test:

a) volumetric efficiency;

b) overall efficiency;

c) effective inlet flow rate;

d) output torque.

In addition, the parameters in Table 7 shall be recorded:

Table 7 — Parameters for motor testing

Parameter	Result	Units
Test fluid used		
Temperature of the test fluid at the motor inlet		K
Ambient temperature		K
Kinematic viscosity of the test fluid used at test temperature		$m^2\ s^{-1}$
Density of test fluid		$kg\ m^{-3}$
Percentage of motor full capacity at which the test was conducted		%
Motor effective outlet pressure		Pa

An example of graphs for motor performance against rotational frequency is given in Figure C.3.

6.4 Integral transmission tests

For testing an integral transmission, the transmission shall be tested at one constant input rotational frequency (constant input power) and a graph shall be plotted of the overall efficiency, η_t, versus the output rotational frequency, n_2.

The test shall be repeated for three different effective outlet powers, $P_{2,e}$. A graph shall be plotted of the rotational frequency ratio, Z, versus the effective pump outlet pressure, p_2.

In addition, the parameters in Table 8 shall be recorded:

Table 8 — Parameters for testing an integral transmission at one constant input rotational frequency (constant input power) testing

Parameter	Result	Units
Test fluid used		
Temperature of the test fluid at the pump inlet		K
Ambient temperature		K
Kinematic viscosity of the test fluid used at test temperature		$m^2\ s^{-1}$
Density of test fluid		$kg\ m^{-3}$
Input rotational frequency		s^{-1}
Effective outlet power		W
Percentage of pump full capacity at which the test was conducted		%
Percentage of motor full capacity at which the test was conducted		%

An example of graphs for integral transmission performance against output rotational frequency is given in Figure C.4.

7 Identification statement

It is strongly recommended to manufacturers who have chosen to conform to this document that the following statement be used in test reports, catalogues and sales literature:

"Basic steady state performance data is determined and presented in accordance with ISO 4409, *Hydraulic fluid power — Positive-displacement pumps, motors and integral transmissions — Methods of testing and presenting basic steady state performance*."

Annex A
(normative)

Errors and classes of measurement accuracy

A.1 Classes of measurement accuracy

Depending on the accuracy required, the test shall be carried out in accordance with one of three classes of measurement accuracy, A, B or C, as agreed between the parties concerned.

NOTE Classes A and B are intended for special cases when it is necessary to have the performance precisely defined.

Attention is drawn to the fact that classes A and B require the use of more accurate apparatus and methods, which increases the test cost.

A.2 Errors

Any device or method used shall, by calibration or comparison with International Standards, have been proven to be capable of measuring the given values with systematic errors not exceeding the limits given in Table A.1.

Table A.1 — Measuring instrument permissible systematic calibration errors

Measuring instrument parameter	Permissible systematic error for classes of measurement accuracy		
	A	B	C
Rotational frequency (%)	±0,5	±1,0	±2,0
Torque (%)	±0,5	±1,0	±2,0
Volume flow rate (%)	±0,5	±1,0	±2,0
Pressure MPa (bar) gauge where $p < 0{,}15$ (1,5)	±0,001 (±0,01)	±0,003 (±0,03)	±0,005 (±0,05)
Pressure MPa (bar) gauge where $p \geq 0{,}15$ (1,5)	±0,05 (±0,5)	±0,15 (±1,5)	±0,25 (±2,5)
Temperature (K)	±0,5	±1,0	±2,0
Mechanical power (%)	—	—	±4,0

NOTE 1 The percentage limits apply to the value of the measured quantity and not to the maximum test value or the maximum reading of the instrument.

NOTE 2 The mean indicated value of an instrument reading can differ from the true mean absolute value of the quantity being measured because of inherent and constructional limitations of the instrument and because of the limitations of its calibrations; this source of uncertainty is called "systematic error".

A.3 Combination of errors

When calculations of power or efficiency are made, the combination of errors involved in the calculation may be determined by the root mean square method including all measured and used in calculation parameters.

EXAMPLE $$\frac{\partial \eta_t}{\eta_t} = \sqrt{\left(\frac{\partial q_V}{q_V}\right)^2 + \left(\frac{\partial p}{p}\right)^2 + \left(\frac{\partial n}{n}\right)^2 + \left(\frac{\partial T}{T}\right)^2}$$

The systematic errors used above, ∂q_V, ∂p, ∂n, and ∂T, are the systematic instrument errors and not the maximum values given in Table A.1. For a more precise summation of errors, refer to [1].

Annex B
(informative)

Pre-test checklist

The following constitutes a checklist to aid in the selection of appropriate items upon which agreement is recommended between the parties concerned prior to beginning testing (it is not always necessary or desirable to agree upon all these items):

a) manufacturer's name;

b) manufacturer's identification (type No., serial No.);

c) manufacturer's component description;

d) direction of shaft(s) rotation;

e) test circuit;

f) manufacturer's installation requirements;

g) filtration equipment used;

h) position of pressure-tapping points;

i) use of pipe losses in calculation;

j) pre-test condition;

k) test fluid (name and description);

l) kinematic viscosity of the test fluid at the test temperature;

m) density of the test fluid at the test temperature;

n) isothermal secant bulk modulus of the test fluid;

o) test-fluid volume coefficient of thermal expansion;

p) test-fluid temperature;

q) maximum permissible casing pressure;

r) pump-inlet pressure;

s) rotational frequencies used during testing;

t) test-pressure values;

u) percentage capacities for variable displacement;

v) reverse-flow requirements;

w) boost-pump information;

x) motor-outlet pressure;

y) reverse-rotation requirements;

z) expression of results;

aa) measurement accuracy class.

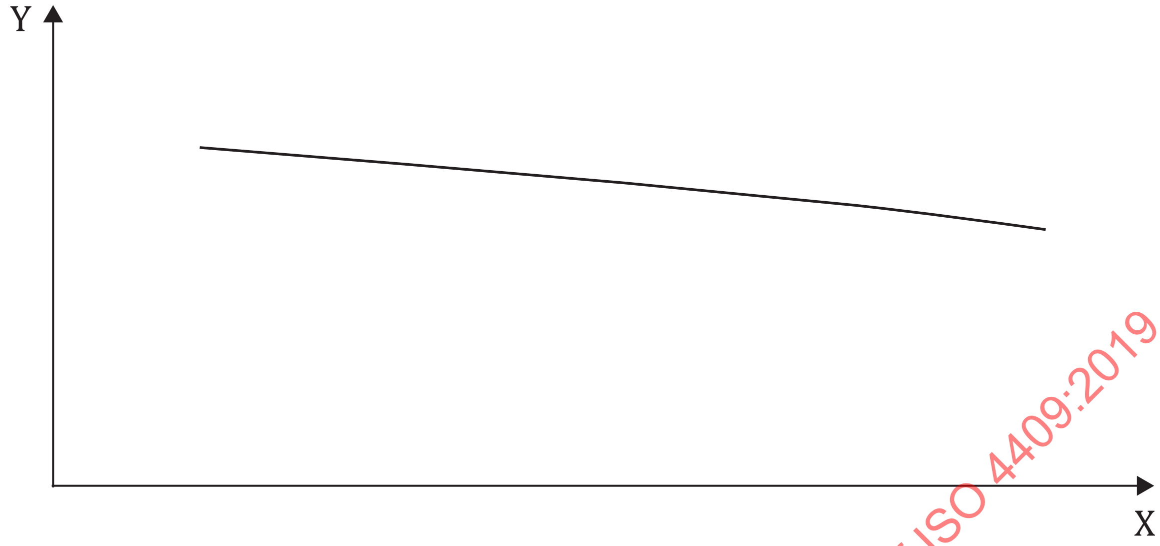
Annex C
(informative)

Suggested formatting for reporting test data

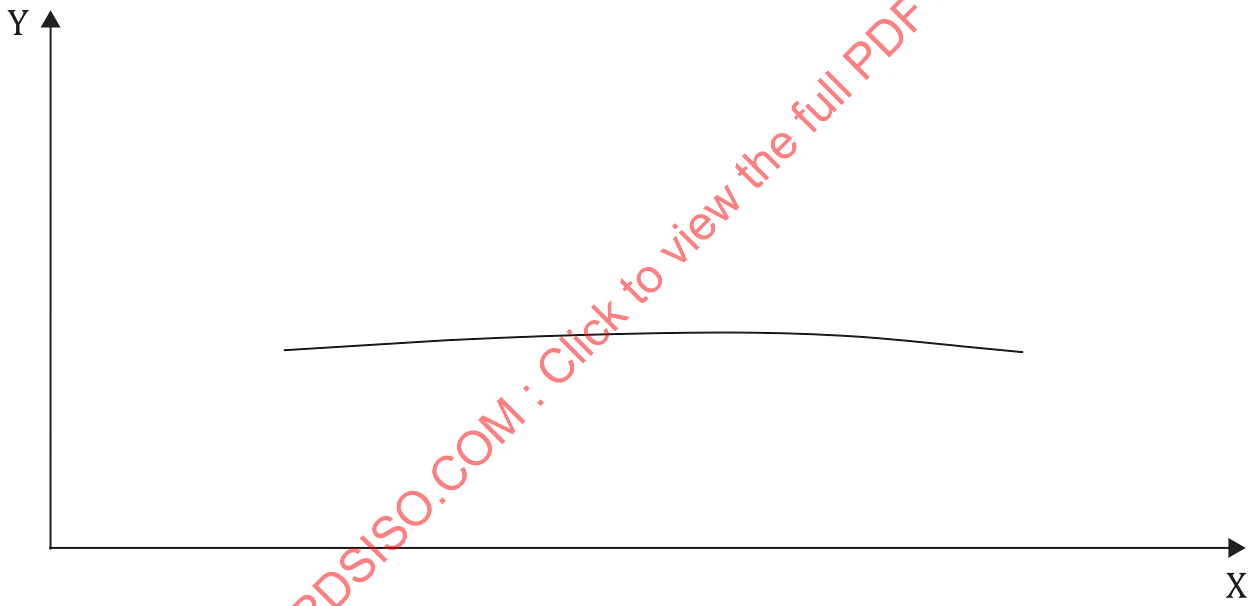
Table C.1 — Suggested chart for presentation of pump or motor performance data

Machine Displacement [Units]	Operating Pressures [Units]						
	Pressure 1	**Pressure 2**	**Pressure 3**	**Pressure 4**	**Pressure 5**	**Pressure 6**	**Pressure 7**
Operating Flow Rates [Units]							
Flow Rate 1	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]
Flow Rate 2	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]
Flow Rate 3	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]
Flow Rate 4	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]
Flow Rate 5	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]
Flow Rate 6	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]
Flow Rate 7	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]
Flow Rate 8	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]	Shaft Torque [Units] Shaft Speed [Units]

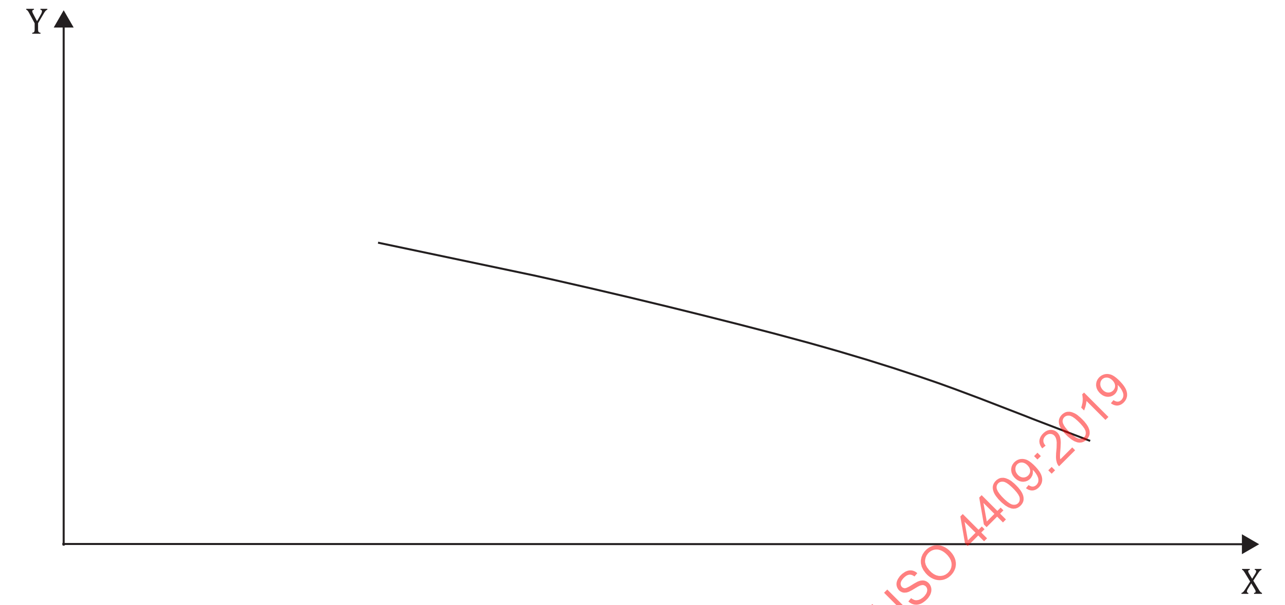
The test data may be presented in numerical form using a chart similar to the example presented in Table C.1. In this chart the machine volumetric displacement (or percent of full displacement for variable displacement units) is recoded at the top left corner. The test pressures are recorded in the first row of the chart. The test flow rate is recorded in the first column to the left of the chart. The measured values of the shaft torque and shaft speed are recorded in each cell corresponding to a respective test pressure and test flow rate.



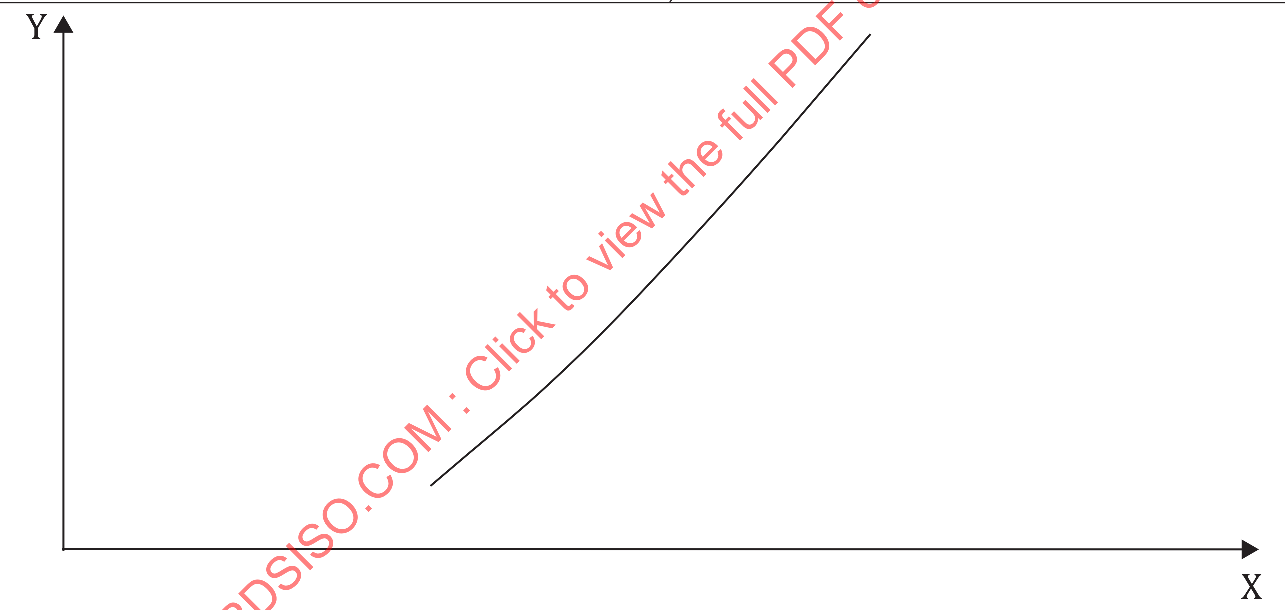
a) **Effective outlet pressure ($p_{2,e}$) versus volumetric efficiency**



b) **Effective outlet pressure ($p_{2,e}$) versus overall efficiency**



c) Effective outlet pressure ($p_{2,e}$) versus effective flow rate



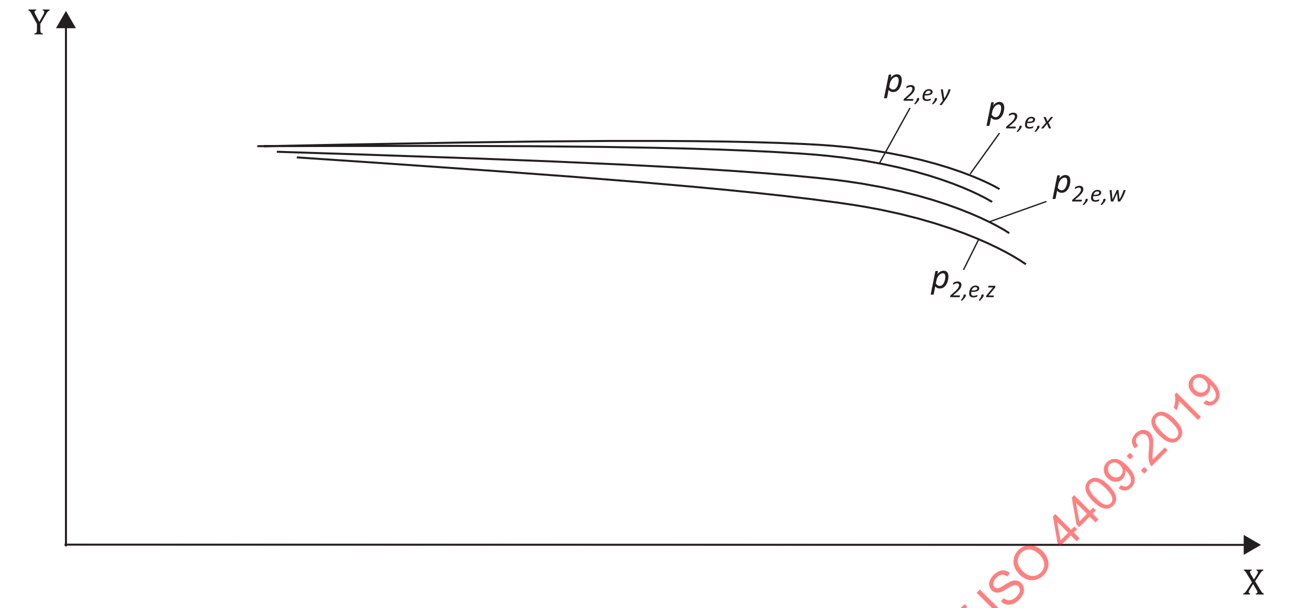
d) Effective outlet pressure ($p_{2,e}$) versus effective inlet mechanical power

Key

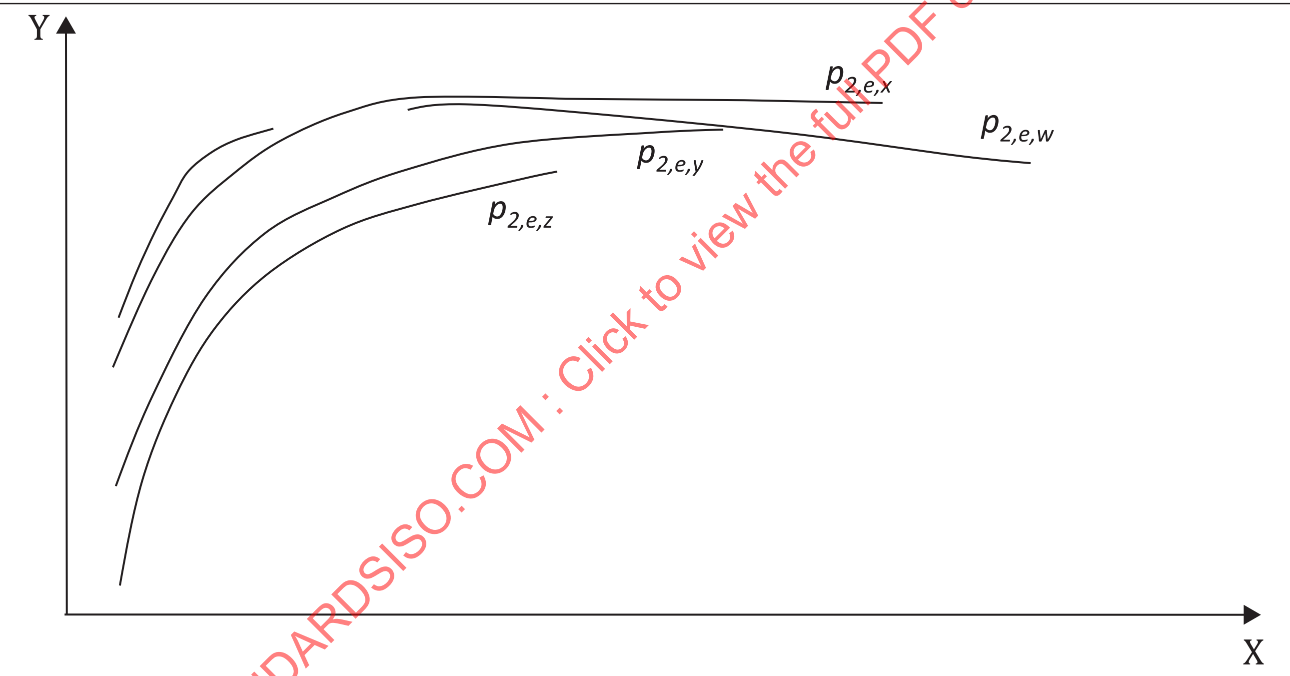
X effective outlet pressure, $p_{2,e}$

Y a) volumetric efficiency, η_V; b) overall efficiency, η_t; c) effective outlet flow rate $q_{v_{2,e}}$; d) effective inlet mechanical power, $P_{1,m}$

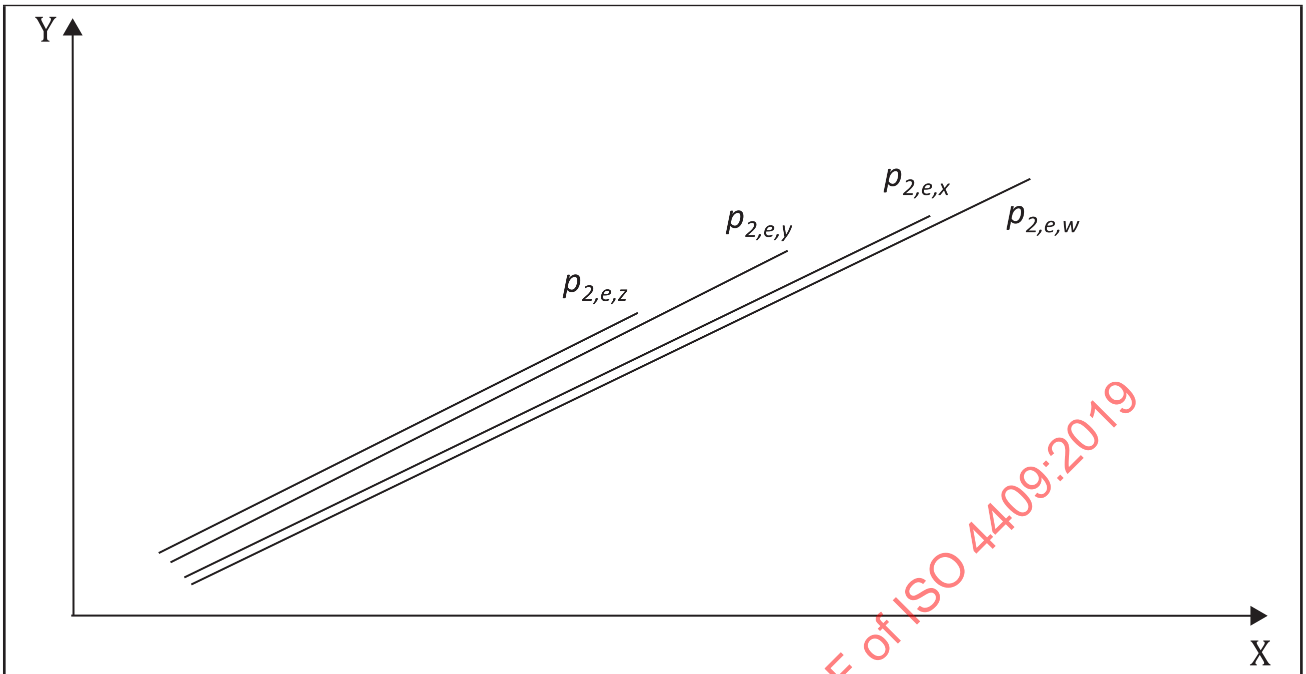
Figure C.1 — Graphs of pump performance against effective outlet pressure



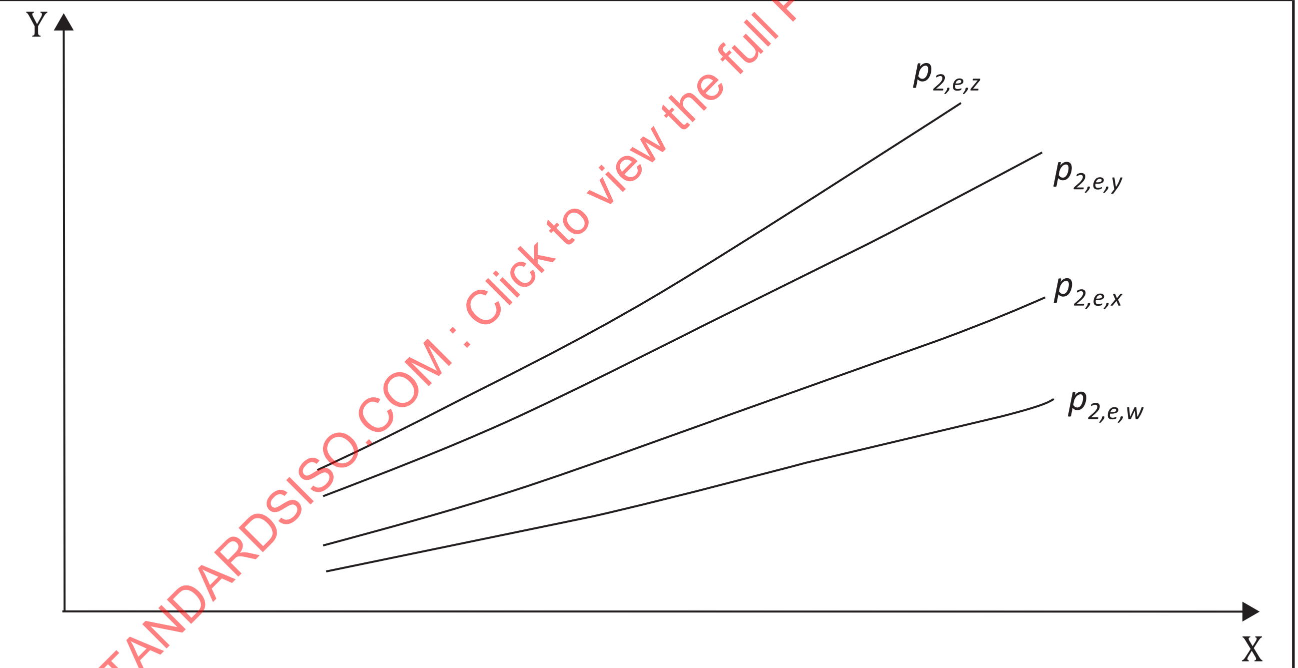
a) Rotational frequency *n* versus volumetric efficiency



b) Rotational frequency *n* versus overall efficiency



c) Rotational frequency *n* versus effective outlet flow rate



d) Rotational frequency *n* versus inlet mechanical power

Key

X rotational frequency, n

Y a) volumetric efficiency, η_V; b) overall efficiency, η_t; c) effective outlet flow rate q_{v_2} ; d) effective inlet mechanical power, $P_{1,m}$

Figure C.2 — Graphs of pump performance against rotational frequency