INTERNATIONAL STANDARD

ISO 4392-1

Third edition
2002-02-15

Hydraulic fluid power — Determination of characteristics of motors —

Part 1: At constant low speed and constant pressure

Transmissions hydrauliques — Détermination des caractéristiques des moteurs —

Partie 1: Essai à pression constante et basse vitesse constante

Reference number
ISO 4392-1:2002(E)

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this part of ISO 4392 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 4392-1 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 4392-1:1989), of which it constitutes a minor revision.

ISO 4392 consists of the following parts, under the general title *Hydraulic fluid power — Determination of characteristics of motors*:

— *Part 1: At constant low speed and constant pressure*

— *Part 2: Startability*

— *Part 3: At constant flow and at constant torque*

Annex A forms a normative part of this part of ISO 4392.

Introduction

In hydraulic fluid power systems power is transmitted and controlled through a fluid under pressure within an enclosed circuit.

Hydraulic motors are units which transform hydraulic energy into mechanical energy, usually with a rotary output.

Hydraulic fluid power — Determination of characteristics of motors —

Part 1:
At constant low speed and constant pressure

1 Scope

This part of ISO 4392 describes a method of determining the low speed characteristics of positive displacement rotary fluid power motors, of either fixed or variable displacement types.

The method involves testing at slow speeds which may generate frequencies having a significant influence upon the steady continuous torque output of the motor and affect the system to which the motor would be connected.

The accuracy of measurement is divided into three classes, A, B and C, which are explained in annex A.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 4392. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 4392 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 3448:1992, *Industrial liquid lubricants — ISO viscosity classification*

ISO 4391:1983, *Hydraulic fluid power — Pumps, motors and integral transmissions — Parameter definitions and letter symbols*

ISO 5598:1985, *Fluid power systems and components — Vocabulary*

ISO 9110-1:1990, *Hydraulic fluid power — Measurement techniques — Part 1: General measurement principles*

ISO 9110-2:1990, *Hydraulic fluid power — Measurement techniques — Part 2: Measurement of average steady-state pressure in a closed conduit*

3 Terms and definitions

For the purposes of this part of ISO 4392, the terms and definitions given in ISO 4391, ISO 5598 and the following apply.

3.1
complete motor cycle
total angular movement of the motor output shaft needed to achieve a repetitive leakage and/or torque recording

NOTE In most motors this will be 360°; however, in some, such as gear motors, it may be several shaft revolutions.

4 Symbols

4.1 The physical quantity letter symbols and their suffixes used in this part of ISO 4392 are in accordance with ISO 4391.

4.2 The graphical symbols used in Figure 1 are in accordance with ISO 1219-1.

5 Test installation

5.1 Hydraulic test circuit

5.1.1 A hydraulic test circuit similar to that shown in Figure 1 shall be used.

This figure does not show all the safety devices necessary to protect against damage in the event of component failure. It is important that those responsible for carrying out these tests give due consideration to safeguarding both staff and equipment.

NOTE 1 Although Figure 1 illustrates a basic circuit to test a bidirectional motor, a similar but suitably modified circuit is acceptable for testing unidirectional motors.

NOTE 2 An additional booster pump circuit may be necessary when testing piston-type motors.

5.1.2 A hydraulic supply (1a and 1b of Figure 1) shall be used and pressure-relief valves (2a and 2b of Figure 1) shall be installed which satisfy the requirements of 8.2.

5.1.3 A fluid conditioning circuit shall be installed which provides the filtration necessary to protect the test motor and the other circuit components and which will maintain the fluid temperatures specified in clause 7.

5.1.4 If the test motor is equipped with an external case drain, the drain shall be connected to the test motor return line so as to measure total flow [see 5.3.1 a)].

Should the safe pressure for the motor casing be exceeded by the above method, the separate case drain flow and return line flow shall be measured simultaneously.

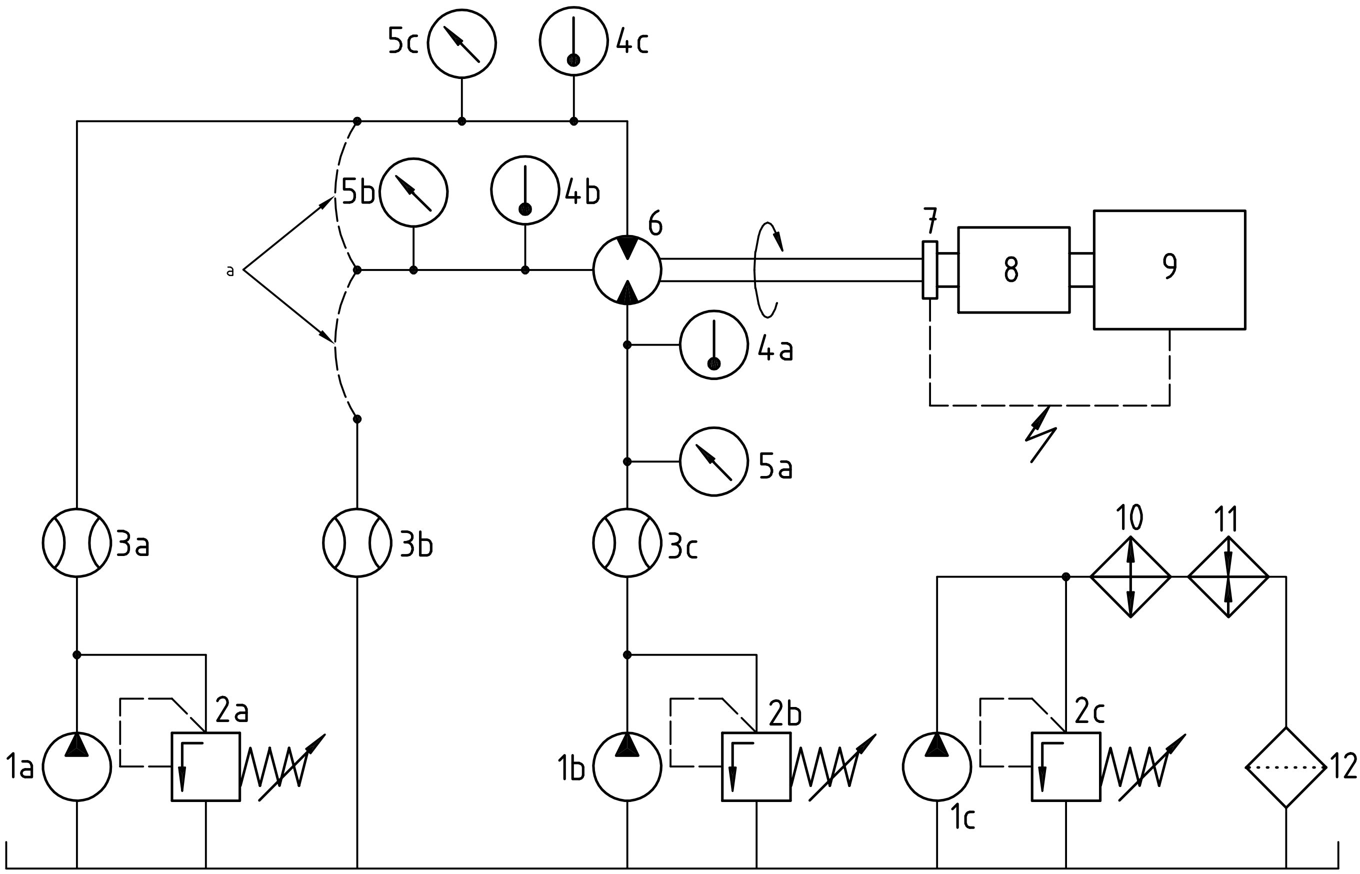
5.1.5 As an alternative to 5.1.4, a high-pressure flowmeter [see 5.3.1 c)] may be installed in the motor inlet line to measure the total flow.

5.1.6 The hydraulic ports of the test motor shall be connected to the hydraulic circuit in such a manner that the motor shaft will rotate in the same direction as the constant speed load.

5.2 Test apparatus

5.2.1 A test rig shall be set up which makes use of the test circuit specified in 5.1 and provides the equipment shown in Figure 1.

5.2.2 A positive locking device shall be provided on continuously variable displacement motors to prevent the displacement inadvertently changing during the pertinent portion of each test.



Main test circuit **Fluid-conditionning circuit**

Key

1a,	1b	1c	Circulating pumps	7	Speed and shaft angle control
2a,	2b,	2c	Pressure-relief valves	8	Torque transducer
3a,	3b,	3c	Flowmeters	9	Adjustable constant speed load [c]
4a,	4b[b],	4c	Temperature indicators	10	Cooler
5a,	5b,	5c	Pressure indicators	11	Heater
	6		Motor being tested	12	Filter

[a] Alternative connections (see 5.1.4).

[b] Optional.

[c] An example of an adjustable constant speed load is a combination of a worm gearbox(es) with a constant speed drive.

Figure 1 — Typical hydraulic test circuit for bidirectional motor

5.3 Instrumentation

5.3.1 Measuring instruments shall be selected and installed to measure the following test motor data:

a) total flow (see 5.1.4);

b) inlet and outlet temperatures;

c) inlet and outlet pressure;

d) inlet flow (see 5.1.5);

e) output torque;

f) output shaft speed and angular displacement.

5.3.2 Instruments shall conform to the requirements of ISO 9110-1 and ISO 9110-2. The systematic errors of the measuring instruments shall be consistent with the chosen class of measurement accuracy (see annex A).

5.3.3 Appropriate recording instruments shall be selected and installed which are capable of resolving signals at frequencies greater than 10 times the highest expected fundamental data frequency.

6 Pretest data

6.1 Using the motor manufacturer's data and other known facts, gather the pretest data as follows:

a) calculate the rated (geometric or theoretical) torque of the motor, $T_{g,\,n}$ or $T_{i,\,n}$, based upon its geometric or theoretical displacement at rated pressure, using the formula

$$T_{g,\,n} = \frac{\Delta p_n \times V_g}{2\pi}$$

or

$$T_{i,\,n} = \frac{\Delta p_n \times V_i}{2\pi}$$

where

Δp_n is the rated differential pressure,

V_g is the geometric swept volume,

V_i is the derived swept volume;

b) determine the number of displacement pulses per revolution of the motor shaft, taking into account any gearing which would influence the frequency;

c) calculate the fundamental data frequency, f_e, in hertz, using the formula

$$f_e = \frac{n_e}{60} \times N$$

where

n_e is the test speed, in reciprocal minutes;

N is the number of displacement pulses [taken from 6.1 b)].

6.2 Using the motor manufacturer's recommended value for rated speed, n_n, calculate the ideal (geometric or theoretical) flow at rated speed, $q_{Vg,\,n}$ or $q_{Vi,\,n}$, using the formula

$$q_{Vg,\,n} = n_n \times V_g$$

or

$$q_{Vi,\,n} = n_n \times V_i$$

6.3 Determine the fluid viscosity in accordance with ISO 3448.

6.4 Estimate the maximum output torque expected to be produced by the motor during the test using the rated torque, $T_{g, n}$ or $T_{i, n}$ as determined in 6.1 a).

7 Test conditions

The following test conditions shall apply:

a) fluid temperature, θ, at motor inlet: either 50 °C or 80 °C;

b) inlet pressures: 100 % and 50 % of rated pressure;

c) back pressure: to be kept constant at a value within the limits given by the motor manufacturer;

d) output shaft speed: the minimum rotational speed in a given direction recommended by the motor manufacturer, or, if not available, 1 min^{-1};

e) displacements: for variable displacement motors, the maximum possible and the minimum recommended by the manufacturer.

8 Test procedure

8.1 Connect the instrumentation and recording apparatus to record differential pressure (or, optionally, inlet and outlet pressure), output torque and total flow (see 5.1.5 for option when outlet pressure exceeds safe limit for case pressure).

Before starting the test, fill the motor case with fluid, if necessary.

8.2 Maintain the measured inlet and outlet pressure constant to ± 2 % of the reading, or 1 bar[1)] (0,1 MPa), whichever is the greater.

8.3 Maintain the output shaft speed within ± 2 % of the mean.

8.4 Maintain the measured inlet fluid temperature constant to ± 2 °C for the duration of a recording. Alternatively, ensure that data are recorded only during those periods when the temperature is within those limits.

8.5 Establish thermal equilibrium before recording each set of test data.

NOTE This may, for example, be achieved by

a) disconnecting the motor from the adjustable constant speed load,

b) operating the motor at rated speed while maintaining the inlet fluid temperature until outlet fluid temperature has stabilized,

c) reconnecting the constant speed load and recording data for the desired combination of test values.

8.6 Make separate simultaneous recordings of each of the variables listed in 8.1 for each combination of test values of differential pressure, inlet temperature, displacement and direction of rotation.

8.7 Extend the recording to as many revolutions as are necessary to achieve one complete motor cycle.

8.8 Record the actual measured values and test values of the corresponding parameters.

8.9 Make a note on the recordings of any tendency of the motor to operate in a jerky or non-uniform manner.

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1) 1 bar = 10^5 Pa; 1 Pa = 1 N/m^2

8.10 When using digital data acquisition techniques, select a sample interval which provides 95 % confidence that the maximum and minimum values of leakage and torque have been determined by pretesting.

8.11 Make a note of any tendency of the motor to be non-repeatable in either torque or leakage.

9 Expression of results

NOTE Refer to clause 4 for a fuller explanation of letter symbols and suffixes.

9.1 Determine the volume flow rate, $q_{V\text{e}, \varphi}$, through the test motor for each recording at selected shaft positions, equally divided over one complete motor cycle.

It should be noted that in the formula

$$q_{V\text{e}, \varphi} = \frac{\omega}{2\pi} V_{\text{i}, \varphi} + q_{V\text{S}, \varphi}$$

since the angular velocity, $\omega = 2\pi n$, is very small, the contribution of volumetric losses at the selected shaft position, $q_{V\text{s}, \varphi}$, is predominant.

In this formula $V_{\text{i}, \varphi}$ is the derived swept volume at the selected shaft position.

9.2 Calculate the mean flow over one complete motor cycle, $q_{V\text{e, ma}}$, using the following formula:

$$q_{V\text{e, ma}} = \frac{q_{V\text{e}, \varphi 1} + q_{V\text{e}, \varphi 2} + q_{V\text{e}, \varphi 3} + \ldots + q_{V\text{e}, \varphi z}}{z}$$

where

the suffixes $\varphi 1$, $\varphi 2$, $\varphi 3$ …φz are the respective selected shaft positions;

z is the number of readings per revolution.

9.3 Calculate the flow irregularity at each selected shaft position, $\Delta q_{V\text{e}, \varphi}$, using the following formula:

$$\Delta q_{V\text{e}, \varphi} = \left| q_{V\text{e, ma}} - q_{V\text{e}, \varphi} \right|$$

9.4 Calculate the mean flow irregularity over one complete motor cycle, $\Delta q_{V\text{e, ma}}$, using the following formula:

$$\Delta q_{V\text{e, ma}} = \frac{\Delta q_{V\text{e}, \varphi 1} + \Delta q_{V\text{e}, \varphi 2} + \Delta q_{V\text{e}, \varphi 3} + \ldots + \Delta q_{V\text{e}, \varphi z}}{z}$$

9.5 Determine the flow irregularity index, Ir_{qV}, using the following formulae:

$$Ir_{qV} = \frac{\Delta q_{V\text{e, ma}}}{q_{V\text{e, ma}}}$$

or

$$Ir_{qV} = \frac{\left| q_{V\text{e, ma}} - q_{V\text{e}, \varphi 1} \right| + \left| q_{V\text{e, ma}} - q_{V\text{e}, \varphi 2} \right| + \left| \ldots \right| + \left| q_{V\text{e, ma}} - q_{V\text{e}, \varphi z} \right|}{q_{V\text{e}, \varphi 1} + q_{V\text{e}, \varphi 2} + \ldots + q_{V\text{e}, \varphi z}}$$

9.6 Calculate the average volumetric efficiency, $\eta_{V,\,ma}$, for the minimum of one motor revolution using the following formula:

$$\eta_{v,\,ma} = \frac{V_{i,\,ma} \times \frac{\omega}{2\pi}}{q_{Ve,\,ma}}$$

where

$V_{i,\,ma}$ is the average derived swept volume;

ω is the angular velocity;

$q_{Ve,\,ma}$ is the average volume flow rate.

9.7 Calculate the relative peak-to-peak value of flow, δq_{Ve}, using the following formula*:*

$$\delta q_{Ve} = \frac{q_{Ve,\,max} - q_{Ve,\,min}}{q_{Ve,\,ma}}$$

9.8 Determine the output torque of the motor for each recording at the selected shaft positions, $T_{e,\,\varphi}$, equally divided over one complete motor cycle using the following formula:

$$T_{e,\,\varphi} = \Delta p \times \frac{V_{i,\,\varphi}}{2\pi} - T_{s,\,\varphi}$$

where

Δp is the differential pressure;

$V_{i,\,\varphi}$ is the derived swept volume at the selected shaft position;

$T_{s,\,\varphi}$ is the torque loss at the selected shaft position.

9.9 Calculate the mean torque, $T_{e,\,ma}$, over one revolution using the following formula:

$$T_{e,\,ma} = \frac{T_{e,\,\varphi 1} + T_{e,\,\varphi 2} + T_{e,\,\varphi 3} + \ldots + T_{e,\,\varphi z}}{z}$$

9.10 Calculate the torque irregularity at each selected shaft position, $\Delta T_{e,\,\varphi}$, using the following formula:

$$\Delta T_{e,\,\varphi} = T_{e,\,ma} - T_{e,\,\varphi}$$

9.11 Calculate the mean torque irregularity, $T_{e,\,ma}$, over one complete motor cycle using the following formula:

$$\Delta T_{e,\,ma} = \frac{\Delta T_{e,\,\varphi 1} + \Delta T_{e,\,\varphi 2} + \Delta T_{e,\,\varphi 3} + \ldots + \Delta T_{e,\,\varphi z}}{z}$$

9.12 Determine the torque irregularity index, Ir_T, using the following formulae:

$$Ir_T = \frac{\Delta T_{e,\,ma}}{T_{e,\,ma}}$$

or

$$Ir_T = \frac{\left|T_{e, ma} - T_{e, \varphi 1}\right| + \left|T_{e, ma} - T_{e, \varphi 2}\right| + \left|\ldots\right| + \left|T_{e, ma} - T_{e, \varphi z}\right|}{T_{e, \varphi 1} + T_{e, \varphi 2} + \ldots + T_{e, \varphi z}}$$

9.13 Calculate the mean hydraulic mechanical efficiency, $\eta_{hm, ma}$, using the following formula:

$$\eta_{hm, ma} = \frac{T_{e, ma}}{\Delta p \times \frac{V_i}{2\pi}}$$

9.14 Calculate the relative peak-to-peak value of torque, δT_e, using the following formula:

$$\delta T_e = \frac{T_{e, max} - T_{e, min}}{T_{e, ma}}$$

10 Test report

10.1 General

All the relevant test data at every test speed and test pressure, and the information listed in 10.3 shall be recorded in a test report.

10.2 Presentation of test data

All test measurements and the results of the calculations derived from the measurements shall be presented in tabular form and, where appropriate, graphically.

10.3 Test data

The following test data shall be included in the test report:

a) a description of the motor;

b) the class of measurement accuracy used (see annex A);

c) a description of the hydraulic test circuit and components;

d) a description of the test fluid;

e) the fluid viscosity (see 6.3);

f) the fluid temperature, θ [see 7 a)];

g) flow as a function of rotational angle at constant pressure and constant speed;

h) torque as a function of rotational angle at constant pressure, constant speed and constant temperature;

i) the geometric swept volume V_g, or derived swept volume V_i;

j) the mean flow over one complete motor cycle, $q_{Ve, ma}$ (see 9.2);

k) the mean flow irregularity over one complete motor cycle, $\Delta q_{Ve, ma}$ (see 9.4);

l) the flow irregularity index, Ir_{qV} (see 9.5);

m) the volumetric efficiency at 1 min^{-1}, $\eta_{\text{v, ma}}$ (see 9.6);

n) the relative peak-to-peak value of flow, $\delta q_{V\text{e}}$ (see 9.7);

o) the mean torque over one complete motor cycle, $T_{\text{e, ma}}$ (see 9.9);

p) the mean torque irregularity over one complete motor cycle, $\Delta T_{\text{e, ma}}$ (see 9.11);

q) the torque irregularity index, Ir_T (see 9.12);

r) the mean hydraulic mechanical efficiency, $\eta_{\text{hm, ma}}$ (see 9.13);

s) the relative peak-to-peak value of torque, δT_{e} (see 9.14).

Annex A
(normative)

Classes of measurement accuracy

NOTE Guidance on measurement accuracy is given in ISO 9110-1 and ISO 9110-2.

A.1 Classes of measurement accuracy

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

NOTE 1 Classes A and B are intended for special cases when there is a need to have the performance more precisely defined.

NOTE 2 Attention is drawn to the fact that class A and B tests require more accurate apparatus and methods, which increase the costs of such tests.

A.2 Errors

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

NOTE The limits given in Table A.1 are of the value of the quantity being measured and not a percentage of the maximum scale reading of the instrument.

Table A.1 — Permissible systematic errors of measuring instruments as determined during calibration

Parameter of measuring instrument	Permissible systematic errors for classes of measurement accuracy		
	A	B	C
Output torque, $T_{2,\,e}$, %	± 1,5	± 3	± 5
Total input/output flow, $q_{V1,\,t,\,e}$ or $q_{V2,\,t,\,e}$, %	± 2	± 4	± 6
Inlet/outlet pressure, $p_{1,\,e}$ and $p_{2,\,e}$, %	± 0,8	± 1,5	± 3
Inlet/outlet temperature, $\theta_{1,\,e}$ and $\theta_{2,\,e}$, °C	± 0,5	± 1	± 2

Bibliography

[1] ISO 1219-1:1991, *Fluid power systems and components — Graphic symbols and circuit diagrams — Part 1: Graphic symbols*

[2] ISO 4409:1986, *Hydraulic fluid power — Positive displacement pumps, motors and integral transmissions — Determination of steady-state performance*

ICS 23.100.10

Price based on 11 pages