International Standard

ISO 15086-2

Second edition
2025-02

Hydraulic fluid power — Determination of the fluid-borne noise characteristics of components and systems —

Part 2: **Measurement of the speed of sound in a fluid in a pipe**

Transmissions hydrauliques — Évaluation des caractéristiques du bruit liquidien des composants et systèmes —

Partie 2: Mesurage de la vitesse du son émis dans un fluide dans une tuyauterie

Reference number
ISO 15086-2:2025(en)

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Foreword

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

This second edition cancels and replaces the first edition (ISO 15086-2:2000), which has been technically revised.

The main changes are as follows:

— the frequency range of pressure ripples has been revised;

— the symbol units, the symbol B_e, subscript O and N have been added to Table 1;

— the symbol f_0 (first acoustic antiresonance frequency) has been replaced by f_{a1};

— Figures 3 and C.1 have been added;

— Figures 1, 2 and 4 have been corrected;

— Formulae 1, C.2, and C.3 have been corrected;

— Annex D has been revised;

— various additional editorial modifications have been made.

A list of all parts in the ISO 15086 series can be found on the ISO website.

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. During the process of converting mechanical power into hydraulic fluid power, flow and pressure ripple and structure-borne vibrations are generated.

Hydro-acoustical characteristics of hydraulic components can be measured with acceptable accuracy if the speed of sound in the fluid is precisely known.

The measurement technique for determining the speed of sound in a pipe, as described in this document, is based upon the application of plane wave transmission line theory to the analysis of pressure ripple in rigid pipes[1].

Two different measurement approaches are presented, namely the use of

— three pressure transducers in a pipe, and

— acoustic antiresonance in a closed-end pipe system.

The three-pressure-transducer method should be used at any time when the speed of sound is to be measured under the effective working conditions in a system. This method can be performed simultaneously with the hydro-acoustical measurement methods specified in ISO 10767-1, ISO 10767-3 and ISO 15086-3, using the same equipment and measurements.

Either method is suitable to produce a table of speed-of-sound data as a function of mean pressure and temperature for a particular fluid.

Hydraulic fluid power — Determination of the fluid-borne noise characteristics of components and systems —

Part 2:
Measurement of the speed of sound in a fluid in a pipe

1 Scope

This document describes the procedure for the determination of the speed of sound in a fluid enclosed in a pipe, by measurements from pressure transducers mounted in the pipe.

This document is applicable to all types of hydraulic circuit operating under steady state conditions, irrespective of size, for pressure pulsations over a frequency range from 10 Hz to 3 kHz.

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 5598, *Fluid power systems and components — Vocabulary*

ISO 80000-1, *Quantities and units — Part 1: General*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5598 and the following 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
flow ripple
fluctuating component of flowrate in a hydraulic fluid, caused by interaction with a flow ripple source within the system

3.2
pressure ripple
fluctuating component of pressure in a hydraulic fluid, caused by interaction with a *flow ripple* (3.1) source within the system

3.3
fundamental frequency
lowest frequency of *pressure ripple* (3.2) measured by the frequency-analysis instrument

3.4
harmonic
sinusoidal component of the *pressure ripple* (3.2) or *flow ripple* (3.1) occurring at an integer multiple of the *fundamental frequency* (3.3)

Note 1 to entry: A harmonic may be represented by its amplitude and phase, or alternatively by its real and imaginary parts.

3.5
hydraulic noise generator
hydraulic component generating *flow ripple* (3.1) and consequently *pressure ripple* (3.2) in the circuit

3.6
measurement pipe
pipe in which the pressure transducers are mounted

3.7
impedance
complex ratio of the *pressure ripple* (3.2) to the *flow ripple* (3.1) occurring at a given point in a hydraulic system and at a given frequency

3.8
acoustic antiresonance frequency
frequency at which the magnitude of the entry *impedance* (3.7) of the *measurement pipe* (3.6) is at a minimum.

4 Symbols

Table 1 — Symbols

Symbol	Description	Unit
A, A', B, B'	Complex coefficients	$m^3 \cdot s^{-1} \cdot Pa^{-1}$
a, b	Frequency-dependent wave propagation coefficients	$rad \cdot s^{-1}$
B_e	Effective bulk modulus of elasticity	Pa
c	Speed of sound in the fluid	$m \cdot s^{-1}$
d	Internal diameter of measurement pipe	m
f	Frequency of the wave pulsation harmonic	Hz
f_i	i^{th} harmonic frequency	Hz
f_{ai}	i^{th} acoustic antiresonance frequency	Hz
H	Transfer function (complex number) between two pressure transducer signals after calibration correction	—
H'	Transfer function (complex number) between two pressure transducer signals under calibration	—
H^*	Transfer function (complex number) between two pressure transducer signals	—
j	Complex operator ($\sqrt{-1}$)	—
L	Distance between transducers 1 and 2 (Method 1)	m
L'	Distance between transducers 2 and 3 (Method 1)	m
l	Distance from PT_1 to the end of the tube (Method 2)	m
P_1	Pressure ripple of transducer PT_1 (complex number)	Pa
P_2	Pressure ripple of transducer PT_2 (complex number)	Pa
P_3	Pressure ripple of transducer PT_3 (complex number)	Pa
$Q_{1 \rightarrow 2}$	Flow ripple at location 1, from 1 to 2 (complex number)	$m^3 \cdot s^{-1}$
$Q_{2 \rightarrow 1}$	Flow ripple at location 2, from 2 to 1 (complex number)	$m^3 \cdot s^{-1}$

Table 1 *(continued)*

Symbol	Description	Unit
$Q_{2\to3}$	Flow ripple at location 2, from 2 to 3 (complex number)	$m^3 \cdot s^{-1}$
S_i	Coherence function corresponding to measurement frequencies, f_i	—
ε	Error (complex number)	—
$\bar{\varepsilon}$	Conjugate of complex number ε (complex number)	—
ε_x	Real part of ε	—
ε_y	Imaginary part of ε	—
ρ	Density of fluid	$kg \cdot m^{-3}$
ν	Kinematic viscosity of fluid	$m^2 \cdot s^{-1}$
ω	Angular frequency ($2\pi f$)	$rad \cdot s^{-1}$
Subscript O	Index for old value	—
Subscript N	Index for new value	—
NOTE H, H', H^*, P_1, P_2, P_3, $Q_{1\to2}$, $Q_{2\to1}$, $Q_{2\to3}$ are all frequency-dependent terms and hence are designated by upper-case letters.		

Units used in this document shall be in accordance with ISO 80000-1.

Graphical symbols used in this document are in accordance with ISO 1219-1 unless otherwise stated.

5 Instrumentation

5.1 Static measurements

The instruments used to measure

a) mean flow (Method 1 only),

b) mean fluid pressure, and

c) fluid temperature

shall at least meet the requirements for "industrial class" accuracy of measurement, i.e. class C as given in Annex A.

5.2 Dynamic measurements

The instruments used to measure pressure ripple shall have the following characteristics:

a) resonant frequency: ≥30 kHz,

b) linearity: ±1 %,

c) preferably include acceleration compensation, and

shall at least meet the requirements for "industrial class" accuracy of measurement, i.e. class C as given in Annex B.

The instruments need not respond to steady-state pressure. It can be advantageous to filter out any steady-state signal component using a high-pass filter. This filter shall not introduce an additional amplitude or phase error exceeding 0,5 % or 0,5° respectively of the current measurement.

5.3 Frequency analysis of pressure ripple

A suitable instrument shall be used to measure the amplitude and phase of the pressure ripple.

The instrument shall be capable of measuring the pressure ripple from the pressure transducers such that, for a particular harmonic, the measurements from each transducer are performed simultaneously and synchronised in time with respect to each other.

The instrument shall have an accuracy and resolution for harmonic measurements of

a) amplitude within: ±0,5 %,

b) phase within: ±0,5°, and

c) frequency within: ±0,5 %

over the frequency range from 10 Hz to 3 kHz.

NOTE Conformity with the above specification results in an uncertainty in measurement of speed of sound of less than ±3 %.

6 Hydraulic noise generator

6.1 General

Any type of hydraulic noise generator may be used, provided that sufficient pressure ripple is created at the pressure transducers to allow accurate measurements to be taken.

EXAMPLE Pumps and motors create a pressure ripple consisting essentially of many harmonics of the fundamental frequency. In these cases, the fundamental frequency is equal to the product of the shaft rotational frequency and the number of gear teeth, vanes, or pistons, etc. (as appropriate to the machine used).

Suitable alternatives include

— an auxiliary valve with a rotating spool allowing flow to pass to the return line over part of its rotation, and

— a high response electrohydraulic valve driven by a frequency generator. The high response electrohydraulic valve may be operated with a white noise signal to obtain significant pressure ripple measurements at each frequency of interest.

6.2 Generator vibration

If necessary, the measurement pipe shall be structurally isolated from the generator to minimize vibration, e.g. when some obvious pipe vibrations are occurring based on on-site experience.

7 Test conditions

7.1 General

The required operating conditions shall be maintained throughout each test within the limits specified in Table 2.

7.2 Fluid temperature

The temperature of the fluid shall be that measured at the entry to the measurement pipe.

7.3 Fluid density and viscosity

The density and viscosity of the fluid shall be known to an accuracy within the limits specified in Table 3.

7.4 Mean fluid pressure

The mean fluid pressure shall be that measured at the entry to the measurement pipe.

7.5 Mean flow measurement

The mean flow shall be measured down-stream of the measurement pipe (Method 1 only).

Table 2 — Permissible variations in tests conditions

Test parameter	Permissible variation
Mean flow	±2 %
Mean pressure	±2 %
Temperature	±2 °C

Table 3 — Required accuracy of fluid property data

Property	Required accuracy
Density	±2 %
Viscosity	±5 %

8 Test rig

8.1 General

If, at any test condition, the pressure ripple amplitudes are too small for satisfactory frequency-spectrum analysis to be performed, an alternative noise generator shall be selected.

The pressure transducers shall be mounted such that their diaphragms are flush, within ±0,5 mm, with the inner wall of the pipe.

Two alternative specifications for the measurement pipe and transducer position are given, in accordance with the method used.

8.2 Thermal insulation

Temperature shall be measured at both ends of the measurement pipe. The difference in temperature between the two ends of the measurement pipe shall not exceed 2 °C at any test condition. If necessary, sufficient thermal lagging shall be applied to the measurement pipe to enable this requirement to be met.

8.3 Method 1: Three-transducer method

8.3.1 This method is suitable when the speed of sound is to be measured at the same time as other hydro-acoustical characteristics of hydraulic components, such as impedance, source flow ripple or transfer matrix coefficients. The measurement pipe shall be installed at the place in the test system where measurement of the speed of sound is needed.

The measurement pipe shall be uniform and straight. Its internal diameter shall be between 80 % and 120 % of the diameter of the pipes, or component ports, to which it is connected. The pipe should be supported in such a manner that vibration is minimized.

For cases where other hydro-acoustic properties are not being measured simultaneously, a pump (and if necessary, a hydraulic noise generator) shall be mounted at one end of the measurement pipe. The other end shall be terminated by a loading valve without free-moving internal parts, such as a needle valve.

Mean pressure shall be measured at the upstream end of the measurement pipe.

8.3.2 Three pressure transducers shall be used for Method 1, configured as shown in Figure 1. The transducer spacing shall be selected according to the standard specifications of hydro-acoustical