BS EN 16644:2014

BSI Standards Publication

Pumps — Rotodynamic pumps — Glandless circulators having a rated power input not exceeding 200 W for heating installations and domestic hot water installations — Noise test code (vibro-acoustics) for measuring structure- and fluid-borne noise

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National foreword

This British Standard is the UK implementation of EN 16644:2014. It supersedes BS EN 1151-2:2006 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee MCE/6, Pumps and pump testing.

A list of organizations represented on this committee can be obtained on request to its secretary.

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ISBN 978 0 580 83316 8

ICS 23.080

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 December 2014.

Amendments issued since publication

Date	Text affected

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 16644

December 2014

ICS 23.080

Supersedes EN 1151-2:2006

English Version

Pumps - Rotodynamic pumps - Glandless circulators having a rated power input not exceeding 200 W for heating installations and domestic hot water installations - Noise test code (vibro-acoustics) for measuring structure- and fluid-borne noise

Pompes - Pompes rotodynamiques - Circulateurs sans presse-étoupe de puissance absorbée n'excédant pas 200 W, destinés au chauffage central et à la distribution d'eau chaude sanitaire domestique - Code d'essai acoustique (vibro-acoustique) pour le mesurage des bruits de structure et hydrauliques

Pumpen - Kreiselpumpen - Umwälzpumpen in Nassläuferbauart mit elektrischer Leistungsaufnahme bis 200 W für Heizungsanlagen und Brauchwassererwärmungsanlagen für den Hausgebrauch - Geräuschprüfvorschrift (vibro-akustisch) zur Messung von Körperschall und Flüssigkeitsschall

This European Standard was approved by CEN on 2 November 2014.

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EUROPÄISCHES KOMITEE FÜR NORMUNG

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Ref. No. EN 16644:2014 E

Contents

Page

Foreword

This document (EN 16644:2014) has been prepared by Technical Committee CEN/TC 197 “Pumps”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2015 and conflicting national standards shall be withdrawn at the latest by June 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 1151-2:2006.

This standard replaces EN 1151-2:2006 as a result of the withdrawal of EN 1151-1 and the issuing of the EN 16297 series as its replacement and is expanded to include cooling systems.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

This document covers the measurement of fluid and structure-borne noise as induced by small glandless circulators having a rated input of ≤ 200 W. It has been prepared in response to the need of having uniform procedures as requirements for noise levels especially in residential housing, tightened by national and European regulations. The issue of airborne noise is covered by other standards.

1 Scope

This European Standard specifies a test code for the vibro-acoustic characterization of glandless circulators with pump housing having a rated power input $P_1 \leq 200W$, intended to be used in heating installations, domestic hot water service installations and cooling systems, and is limited to glandless circulators with threaded connections of 11/2 inch. The test code comprises the test rig, the measurement method and the test conditions.

This European Standard applies to glandless circulators, which are manufactured after the date of issue of this European Standard.

The characterization principle is based on measuring the structure-borne and the fluid-borne power transmitted respectively by vibration and pressure fluctuations in the pipe connected to a glandless circulator.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 16297-1:2012, *Pumps — Rotodynamic pumps — Glandless circulators — Part 1: General requirements and procedures for testing and calculation of energy efficiency index (EEI)*

EN 50160, *Voltage characteristics of electricity supplied by public distribution networks*

ISO 2016, *Capillary solder fittings for copper tubes — Assembly dimensions and tests*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 16297-1:2012 and the following apply.

3.1
speed setting
setting attained (for pumps with different settings) when the speed of the electric motor is changed

3.2
fluid-borne intensity
I_{fb}
time averaged rate of flow of the acoustic energy per cross section of fluid transmitted lengthways the straight pipe by internal pressure fluctuations

Note 1 to entry: Its sign can be positive or negative indicating the sense of energy propagation.

Note 2 to entry: Fluid-borne intensity is expressed in W/m^2.

3.3
fluid-borne power
P_{fb}
net acoustic power emitted by a source of pressure fluctuations in the connected straight pipe ⟨glandless circulators⟩

Note 1 to entry: Fluid-borne power is always positive.

Note 2 to entry: Fluid-borne power is expressed in W.

3.4
structure-borne intensity
I_{sb}
time averaged rate of flow of the vibrational energy per unit of length transmitted lengthways the straight pipe by vibration

Note 1 to entry: Its sign can be positive or negative indicating the sense of energy propagation.

Note 2 to entry: I_{sb} is an average of the structure borne intensity over the pipe wall thickness and is therefore expressed in W/m.

3.5
structure-borne power
P_{sb}
net vibration power emitted by a source of vibration in the connected straight pipe ⟨glandless circulators⟩

Note 1 to entry: Structure-borne power is always positive.

Note 2 to entry: Structure-borne power is expressed in W.

3.6
coefficient of fluid-borne energy reflection
R_{fb}
ratio between the net fluid-borne power reflected by pipework discontinuities and the net fluid borne power emitted in a straight pipe by a pump ⟨glandless circulators⟩

Note 1 to entry: Pipework discontinuities covers bends, obstructions, section changes, pipe fixations etc.

Note 2 to entry: This coefficient is always positive and is non-dimensional.

3.7
coefficient of structure-borne energy reflection
R_{sb}
ratio between the net structure-borne power reflected by pipework discontinuities and the net structure borne power emitted in a straight pipe by a pump ⟨glandless circulators⟩

Note 1 to entry: Pipework discontinuities covers bends, obstructions, section changes, pipe fixations etc.

Note 2 to entry: This coefficient is always positive and is non-dimensional.

3.8
fluid-borne power level
L_{Wfb}
logarithmic measure of the fluid-borne power emitted in the straight pipe by a source ⟨glandless circulators⟩

3.9
structure-borne power level
L_{Wsb}
logarithmic measure of the structure-borne power emitted in the straight pipe by a source ⟨glandless circulators⟩

3.10
steady state temperature period
period of time during which the variation of temperature on the motor and on the body of the glandless circulator is contained between limits specified by the manufacturer

3.11
booster pump
any type of pump that maintains the flow

4 Symbols and units

For the purpose of this document, the symbols, quantities and units given in Table 1 apply.

Table 1 — Symbols and units

Symbol	Quantity	Unit
g	Acceleration due to gravity	m/s^2
H	Head (water gauge)	m
P_1	Rated power input	W
p	Pressure	bar
$p_{2max\ o}$	Maximum outlet working pressure	bar
Q	Flow rate	m^3/h
T	Temperature	°C
T_F	Fluid temperature at inlet port	°C
v	Average velocity of water	m/s
ρ	Density	kg/m^3

5 Test rig

5.1 General

The fluid- and structure-borne powers are determined from measurement data acquired from the test rig.

Components and assembly of the test-rig are described below. To get repeatable and reproducible results of the measurements, a rig, which is in accordance with or corresponds to all specifications and assembly advice given here, shall be used.

5.2 Main components of test rig

The test rig is illustrated in Figure 1 and its main components are given in Table 2.

Table 2 — Main components of test rig

No.	Component	Purpose
1	Glandless circulator	Test object: source of pressure pulsation and vibration.
2	Vibration measurement pipe	Acquisition of vibration data allowing the determination of the structure-borne power.
3	Solid anechoic termination	Device absorbing structure-borne power.
4	Pressure pulsation measurement pipe	Acquisition of pressure fluctuation data allowing the determination of the fluid-borne power.
5	Liquid anechoic termination	Device absorbing fluid-borne power.
6	Water tank	Acoustical isolation of the regulation valve.
7	Pressure vessel	Device equalizing the system pressure.
8	Flow meter	Measurement of flow rate
9	Regulation valve	Flow rate regulation
10	Pipe supports	Connecting devices of pipework with frame.
11	Frame	Metal structure.

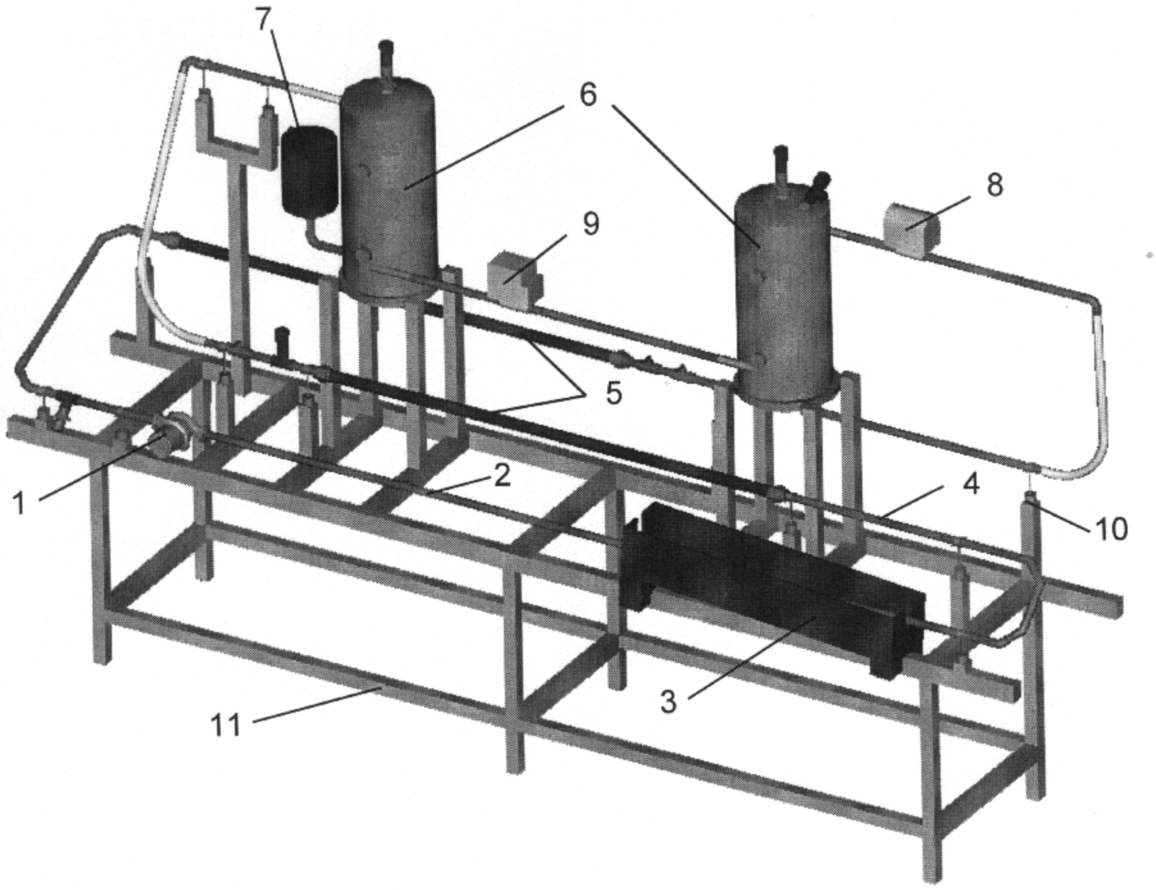


Figure 1 — Test rig

5.3 Specification of test rig components

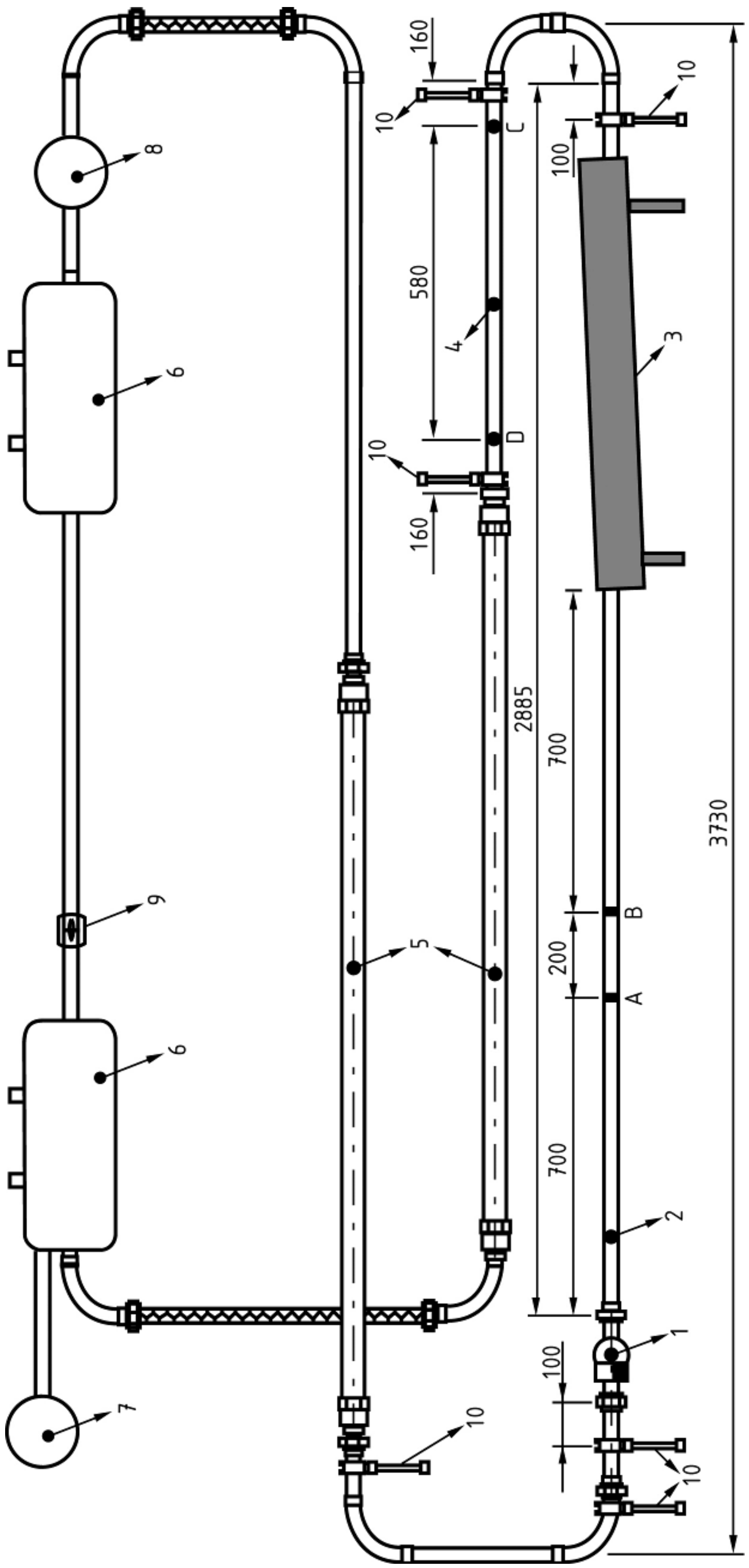
Table 3 provides the necessary overview of the specified components of the test rig shown in Figure 2.

Table 3 — Specification of components

Ref.		Component/Part	Qty.	Specification/Remark
1		**Glandless circulator**		
	1	Pump housing	1	According to EN 16297–1
	2	Washer	2	Non absorbing fibre type
2		**Vibration measurement pipe**		
	1	Pipe		Usual commercial, Copper, ext. diam. approx. 28 mm, wall thickness 0,9 mm – 1 mm
	2	Union nut	2	Usual commercial
	3	Insert	2	Usual commercial, soldered conn. diam. approx 28 mm
	4	Accelerometer	4	Calibration according to 5.8
3		**Solid anechoic termination**		Propagation coefficient curve according to 5.9
	1	Sand box	1	Wood or plastic, wall thickness approx. 10 mm
	2	Pipe cover	1	Usual commercial, plastic foam, wall thickness 10 mm
	3	Sand	10kg	Fine grain 30 µm – 300 µm, medium grain size 130 µm
4		**Pressure pulsation measurement pipe**		
	1	Bend	4	Copper, diam. approx. 28 mm, Form A according to ISO 2016
	2	Pipe		Copper, ext. diam. approx. 28 mm, wall thickness 0,9 mm – 1 mm usual commercial
	3	Sensor adapter	2	Welding socket piece for flush mounted sensor
	4	Pressure transducer	2	Calibration according to 5.8
5		**Liquid anechoic termination**		Propagation coefficient curve acc. To 5.9
	1	Terminator	2	Length 1580 mm, diam. approx. 30 mm
	2	Pipe connection	4	Union, usual commercial, inox steel
6		**Water tank**		
	1	Tank	2	Non-corrosive, volume approx. 50 l
	2	Support	8	Connection to frame, screw fixed
	3	Intermediate connection	1	Usual commercial stainless steel or copper, ext. diam. approx. 28 mm
	4	Pipe connection	2	Flexible tube
7		**Pressure vessel**		
	1	Membrane or pressure tank	1	Usual commercial
8		**Flow meter**		

1	Flow meter	1	An appropriate flow meter forming an integrated part of the test arrangement
9	**Regulation valve**		
1	Valve	1	Usual commercial
10 1 2 3	**Pipe support** Support bar Clip Rubber insert		
11 1	**Frame** Profile		 Massive or hollow, iron or aluminium
12	**Miscellaneous** Inlet/outlet valve Manometer Air separator Shut-off valve		
The test rig may be equipped with additional elements, which are necessary for the trouble-free operation of the water circuit. Such parts shall be installed (in flow direction) behind the 1st and in front of the 2nd liquid anechoic terminator. No additional element exceeding the specified parts is allowed in the remaining test loop area where the measurements take place between and including the fluid anechoic terminations.			

Dimensions in mm



Key

1 glandless circulator

2 vibration measurement pipe

3 adjustable solid anechoic termination

4 pressure pulsation measurement pipe

5 liquid anechoic termination

6 water tank

7 pressure vessel

8 flowmeter

9 regulation valve

10 pipe support

A and B: arrays of accelerometer

C and D: pressure pulsation transducer

Figure 2 — Test rig dimensions

5.4 Assembly

All components shall be mounted free of remaining tensions. Standard sealing means like PTFE bands may be used for pipe connections if not otherwise specified.

Torques of screws of fittings and pipe connections shall meet the supplier's specifications.

The lengths of the support bars (see Figure 2, Ref. 10) carrying the pipe sections for data acquisition and connecting them with the frame shall be adjusted for equalized load distribution.

No contact between walls of the sand box and pipe is allowed.

5.5 Foundation

The test rig shall be established on rigid (concrete) ground. The reacting forces between frame columns and floor shall be adjusted carefully. To avoid tensions in the frame structure it is recommended to use adjustable elements or screws with or without damping elements for equalized loads of all carrying columns.

5.6 Qualifications

After completion the rig has to withstand a pressure test of 4 bar overpressure without leakage. The typical hydraulic losses of the pipe loop shall not exceed 2 m at a flow of 2 m^3 /h.

A booster pump between the tanks is allowed.

5.7 Instrumentation

5.7.1 Measurement of pressure fluctuations

Two sensors of pressure fluctuations shall be flush mounted as shown in Figure 3 at points C and D (see Figure 2) on the pressure pulsation measurement pipe.

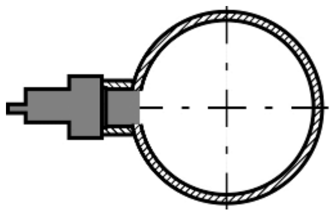
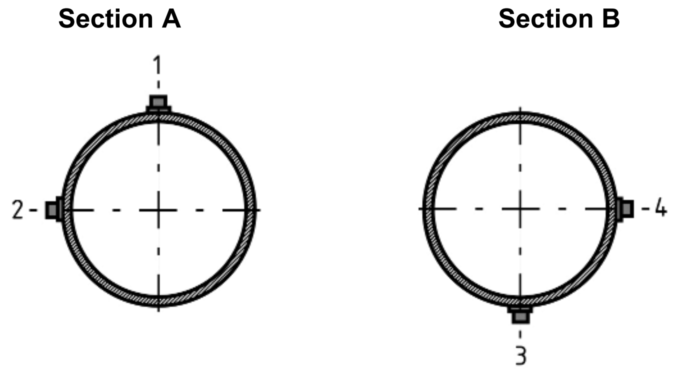


Figure 3 — Flush mounted sensor

5.7.2 Measurement of vibration

Four accelerometers arranged in two arrays as shown in Figure 4 are to be mounted at cross-sections A and B (see Figure 2) on the vibration measurement pipe. The mass of each accelerometer should be lower than 5 g.



Key

1 position of accelerometer 1

2 position of accelerometer 2

3 position of accelerometer 3

4 position of accelerometer 4

Figure 4 — Arrangement of accelerometers

5.8 Calibration

5.8.1 Accelerometers

Lightweight accelerometers shall be used, the mass of which is not greater than 5 g, and having a high sensitivity (100mV/g).

5.8.2 Pressure transducers

It is recommended to use dynamic pressure transducers, with a high sensitivity (15 pC/bar) and compensation for vibration.

5.8.3 Calibration of accelerometers and pressure transducers

The calibration of the instruments shall be done at least once a year. The following criteria should be satisfied:

— Phase angle between 2 pressure transducers should be inferior to ± 1°.

— Amplitude difference between 2 pressure transducers should be inferior to ± 5 %.

5.9 Propagation coefficients

The typical propagation coefficients for solid anechoic termination (S.A.T) and liquid anechoic termination (L.A.T) are shown in Figures 5 and 6.

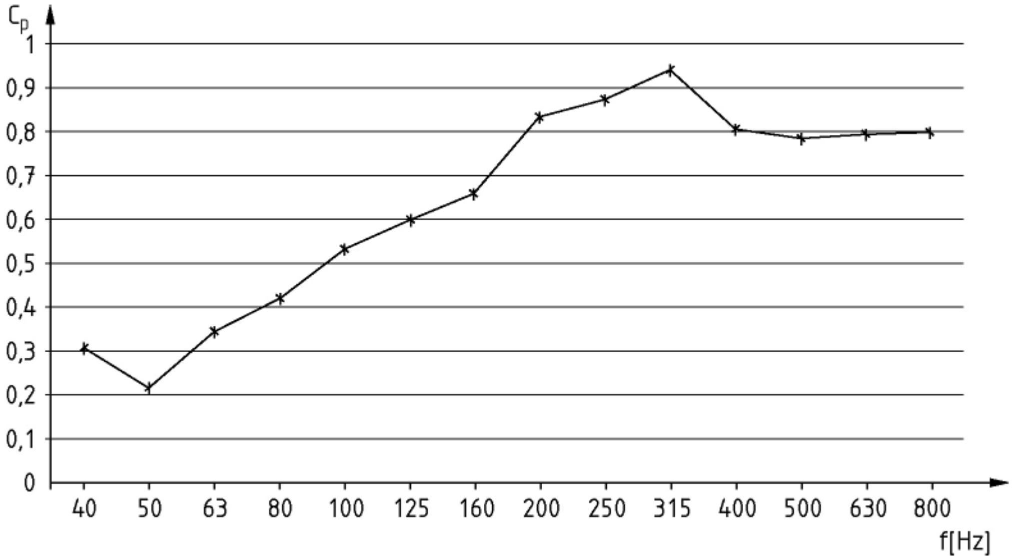


Figure 5 — Propagation coefficient curve (vibration) for solid anechoic termination (S.A.T.)

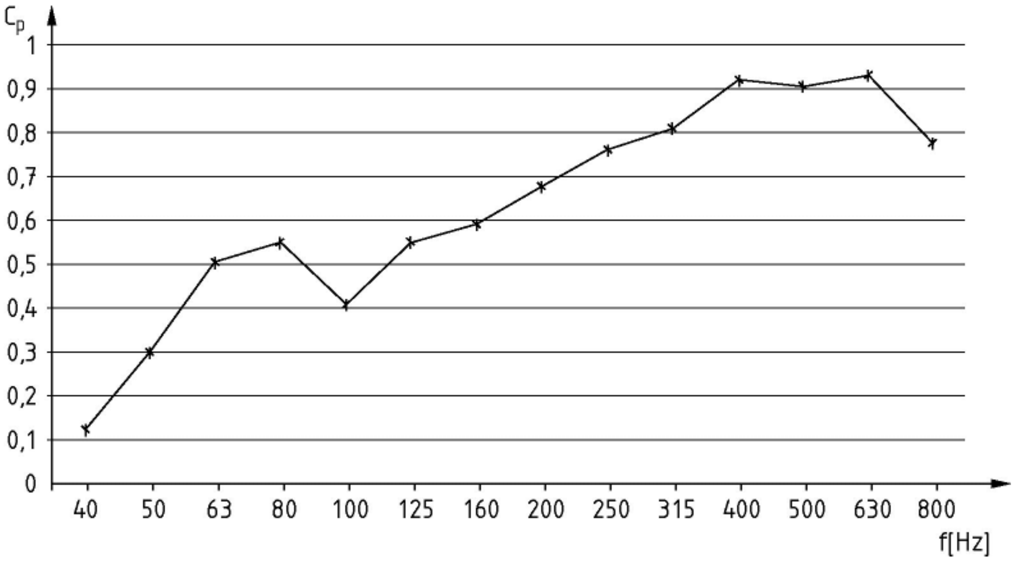


Figure 6 — Propagation coefficient curve (pulsation) for liquid anechoic termination (L.A.T.)

6 Installation and operation

6.1 Installation

The outlet of a glandless circulator to be tested shall be connected to the vibration measurement pipe.

Non-absorbing fibre type joints shall be mounted on fittings of the glandless circulator, e.g. fibre gaskets.

If not specified by the supplier, a fastening torque of 5 Nm shall be applied to fitting of screw connections of the glandless circulator.

The test rig shall be filled with water and completely degassed as well as the glandless circulator.

6.2 Operating parameters

6.2.1 General

The flow rate shall be at maximum speed and in the point where the product of the flow rate and the head reaches the maximum value (see Figure 7, point 1).

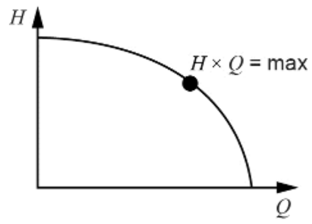


Figure 7 — Hydraulic performance values

6.2.2 Test conditions

6.2.2.1 Water quality

The test system shall be supplied with clean water without solids having a temperature of 20 °C ± 5 °C. Care shall be taken that the water is free of bubbles.

6.2.2.2 Static pressure

A static pressure of 2 bar $\begin{pmatrix} +0,5 \\ 0 \end{pmatrix}$ bar shall be maintained in the test system.

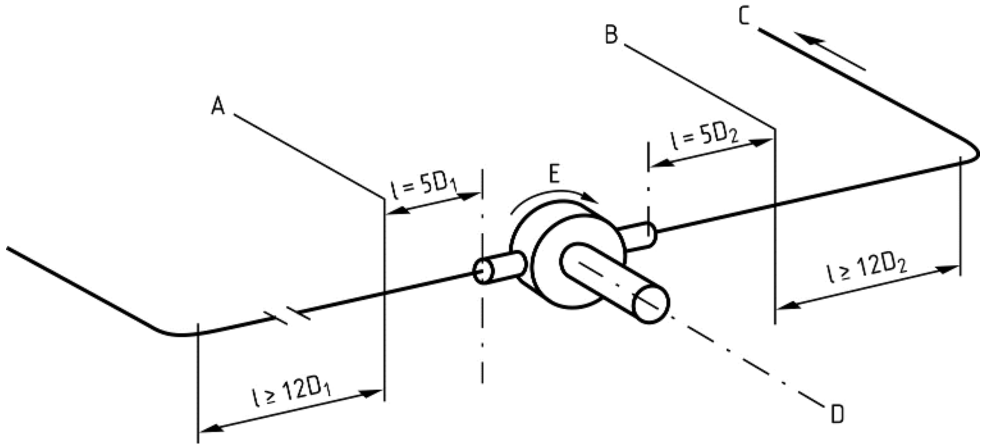
6.2.2.3 Motor input voltage

The nominal voltage of the power supply shall be sinusoidal in accordance with EN 50160 with a tolerance of ± 2 %, the input being maintained at a constant level.

6.2.2.4 Test circuit

The glandless circulator is connected to an open or a closed test arrangement that conforms to Figure 8.

The arrangement shall be made so that it is possible to control the temperature of the water (adding new water or cooling).



Key

A point of measurement of positive input pressure

B point of measurement of positive output pressure

C to measurement of Q and circuit regulating valve

D motor shaft - horizontal

E flow direction

D_1 inside diameter of pipe and glandless circulator inlet

D_2 inside diameter of pipe and glandless circulator outlet

Figure 8 — Test circuit

6.3 Initial operation time

The initial operation time covers the period of time between the instant of switching on the glandless circulator and the instant of the first measurement. This initial operation is required for:

— complete degassing of the test rig and the glandless circulator;

— achievement of the established operating regime according to parameters given in 6.2;

— achievement of the steady-state temperature period of a tested glandless circulator.

7 Factors influencing measurements

7.1 Electromagnetic surroundings

Surrounding equipment producing high electromagnetic fields can seriously parasitize measurements. The coexistence of such devices and the test rig in the same room shall be prevented.

7.2 Earth loops

Earth loops established through the cabling of sensors parasitize measurements in the set of discrete frequencies taking values at 50 Hz and its multiples. These parasites shall be minimised by a careful realization of sensors cabling.

7.3 Vibration surroundings

A glandless circulator being a low level vibration source, vibration measurements can be affected by any secondary vibration source of high level vibration. The co-existence of such sources and the test rig in the same room shall be prevented.

8 Determination of fluid- and structure-borne powers

8.1 Frequency range

The fluid- and structure-borne powers are determined in the frequency band between 40 Hz and 800 Hz.

NOTE Frequency response measurements with forced excitation at the glandless circulator may reveal problems in the low frequency area, when measuring structure-borne power, where the response may change significantly with only small changes in frequency of excitation. This means that the speed of the glandless circulator may very much influence the low frequency power flow below 100 Hz.

8.2 Measurement parameters

8.2.1 Pressure fluctuation measurement parameters

The pressure fluctuation measurement parameters are given in Table 4.

Table 4 — Pressure fluctuation measurement parameters

Parameter	Description	Unit
G_{CC}	narrow-band auto-power spectrum of the signal from the pressure transducer C[1)]	Pa^2
G_{DD}	narrow-band auto-power spectrum of the signal from the pressure transducer D[1)]	
G_{CD}	narrow-band cross-power spectrum between signals from pressure transducers C[1)] and D [1)] with the signal from the transducer C as reference [1)]	
1) See Figure 2.		

8.2.2 Vibration measurement parameters

The vibration measurement parameters are given in Table 5.

Table 5 — Vibration measurement parameters

Parameter	Description	Unit
G_{11}	narrow-band auto-power spectrum of the signal from the accelerometer 1 (array A)[1)]	m^2/s^4
G_{22}	narrow-band auto-power spectrum of the signal from the accelerometer 2 (array A)[1)]	
G_{33}	narrow-band auto-power spectrum of the signal from the accelerometer 3 (array B)[1)]	
G_{44}	narrow-band auto-power spectrum of the signal from the accelerometer 4 (array B)[1)]	
G_{13}	narrow-band cross-power spectrum between signals from accelerometers 1 and 3 with the signal from the accelerometer 1 as reference	
G_{24}	narrow-band cross-power spectrum between signals from accelerometers 2 and 4 with the signal from the accelerometer 2 as reference	
1) See Figures 2 and 4.		

8.3 Sense of power propagation

The sense of propagation of the structure- or the fluid-borne power is determined by means of the sign of the coefficient of the structure- or fluid-borne power propagation.

Positive signs of these coefficients indicate the sense of water flow in the vibration and pressure fluctuation measurement pipes - the sense of power propagation thus goes from the power source (i.e. the glandless circulator) to the power receivers (i.e. anechoic terminations).

8.4 Fluid-borne power determination

8.4.1 General

In the frequency range of interest (see 8.1), the transfer of net acoustic power is achieved by means of plane waves propagating in the water inside the pipe.

8.4.2 Fluid-borne intensity

Determine the fluid-borne intensity, *I*fb in W/m², by the formula:

$$I_{\text{fb}} = -\left(\frac{1}{\rho_{\text{f}} c_{\text{fb}}} \times \frac{\Im\{G_{\text{CD}}\}}{\sin\left(2\pi f \frac{\delta_{\text{CD}}}{c_{\text{fb}}}\right)} \right) \left[\text{W/m}^2\right] \quad (1)$$

And calculate the coefficient of fluid-borne energy reflection, R_{fb}, by the formula.

$$R_{\text{fb}} = \frac{G_{\text{CC}} + G_{\text{DD}} - 2\left[\Re\{G_{\text{CD}}\}\cos\left(\frac{2\pi f \delta_{\text{CD}}}{c_{\text{fb}}}\right) - \Im\{G_{\text{CD}}\}\sin\left(\frac{2\pi f \delta_{\text{CD}}}{c_{\text{fb}}}\right)\right]}{G_{\text{CC}} + G_{\text{DD}} - 2\left[\Re\{G_{\text{CD}}\}\cos\left(\frac{2\pi f \delta_{\text{CD}}}{c_{\text{fb}}}\right) + \Im\{G_{\text{CD}}\}\sin\left(\frac{2\pi f \delta_{\text{CD}}}{c_{\text{fb}}}\right)\right]} \quad (2)$$

where:

G_{CD}	is the measured cross-power spectrum (see 8.2.1);
G_{CC}, G_{DD}	are the measured auto-power spectra (see 8.2.1);
$\Im\{\ \}$	is the designation of the imaginary part of the complex quantity between {};
$\Re\{\ \}$	is the designation of the real part of the complex quantity between {};
f	is the frequency in Hz;
c_{FB} = 1188,6 m/s	is the propagation speed of plane waves in the water-filled pressure pulsation measurement pipe of dimension given in 5.3;
δ_{CD}	is the spacing between the transducers C and D (see Figure 2);
ρ_{W}	is the mass density of the water.

8.4.3 Fluid-borne power

Calculate the fluid-borne power, P_{fb} in W, by the formula:

$$P_{fb} = \frac{\pi d_i^2 I_{fb}}{4(1 - R_{fb})} [W] \quad (3)$$

where:

d_i is the internal diameter of the pipe (see 5.3);

I_{fb} is the fluid-borne intensity as given by Formula (1);

R_{fb} is the coefficient of fluid-borne energy reflection as given by Formula (2).

8.5 Structure-borne power determination

8.5.1 General

In the frequency range of interest (see 8.1), the transfer of net vibrational power is achieved by means of bending waves propagating in the pipe wall.

8.5.2 Structure-borne intensity

Calculate the structure-borne intensity, I_{sb} in W/m, by the formula:

$$I_{sb} = 2 \times K_{sb} \times \frac{\Im\{G_{13} + G_{24}\}}{16(\pi f)^4 \sin(k_{sb}\delta_{AB})} [W/m] \quad (4)$$

and calculate the coefficient of structure-borne energy reflection by the formula:

$$R_{sb} = \frac{\sum_{l=1}^{4} G_{ll} + 2\left[\Re\{G_{13} + G_{24}\}\cos(k_{sb}\delta_{AB}) - \Im\{G_{13} + G_{24}\}\sin(k_{sb}\delta_{AB})\right]}{\sum_{l=1}^{4} G_{ll} + 2\left[\Re\{G_{13} + G_{24}\}\cos(k_{sb}\delta_{AB}) + \Im\{G_{13} + G_{24}\}\sin(k_{sb}\delta_{AB})\right]} \quad (5)$$

where:

G_{13}, G_{24} are the measured cross-power spectra (see 8.2.2);

$G_{ll,\ l\ =\ 1,\ \ldots,\ 4}$ are the measured auto-power spectra (see 8.2.2);

$\Im\{\}$ is the designation of the imaginary part of the complex quantity between {};

$\Re\{\}$ is the designation of the real part of the complex quantity between {};

f is the frequency in Hz;

δ_{AB} is the spacing between accelerometer arrays A and B (see Figure 2);

k_{sb} is the bending wave number in m^{-1} (see Annex A);

K_{sb} is the associated dimensional constant in Ws^4/m^3 (see Annex A).

8.5.3 Structure-borne power

Calculate the structure-borne power, P_{sb} in W, by the formula:

$$P_{sb} = \frac{\pi (d_i + d_e) I_{sb}}{2(1 - R_{sb})} [W] \tag{6}$$

where:

d_e	is the external diameter of the pipe (see 5.3);
d_i	is the internal diameter of the pipe (see 5.3);
I_{sb}	is the structure-borne intensity as given by Formula (4);
R_{sb}	is the coefficient of structure-borne energy reflection as given by Formula (5).

8.6 Overall values of power

Overall fluid-(or structure-) borne power, in W, characterizing the test, is obtained by summing all spectral components of fluid-(or structure-) borne power in the frequency band of interest:

$$P_{fb}^{tot} = \sum_{f_n = f_0}^{f_1} P_{fb}(f_n)[W], \quad \begin{array}{l} f_0 = 40\text{Hz} \\ f_1 = 800\text{Hz} \end{array} \tag{7}$$

$$P_{sb}^{tot} = \sum_{f_n = f_0}^{f_1} P_{sb}(f_n)[W], \quad \begin{array}{l} f_0 = 40\text{Hz} \\ f_1 = 800\text{Hz} \end{array} \tag{8}$$

The number of frequency lines and the type of weighting window used during data acquisition should be taken into account when processing the data.

8.7 Coefficients of energy propagation and power levels

8.7.1 Coefficient of fluid-borne energy propagation

Calculate the coefficient of fluid-borne energy propagation by the formula:

$$C_{fb} = \left\{ \begin{array}{ll} 1 - R_{fb} & \text{if } R_{fb} \le 1 \\ -1 + \dfrac{1}{R_{fb}} & \text{otherwise} \end{array} \right\} \tag{9}$$

NOTE C_{fb} is the complement of the coefficient of fluid-borne energy reflection. This coefficient is non-dimensional and limited in value ($-1 \le C_{fb} \le 1$). Its sign indicates the sense of energy propagation. If this coefficient equals 0, there is no propagation of power lengthways the pipe.

8.7.2 Coefficient of structure-borne energy propagation

Calculate the coefficient of structure-borne energy propagation by the formula:

$$C_{sb} = \left\{ \begin{array}{ll} 1 - R_{sb} & \text{if } R_{sb} \le 1 \\ -1 + \dfrac{1}{R_{sb}} & \text{otherwise} \end{array} \right\} \tag{10}$$

NOTE C_{sb} is the complement of the coefficient of structure-borne energy reflection. This coefficient is non-dimensional and limited in value ($-1 \le C_{sb} \le 1$). Its sign indicates the sense of energy propagation. If this coefficient equals 0, there is no propagation of power lengthways the pipe.

8.7.3 Fluid-borne power level

Calculate the fluid-borne power level by the formula:

$$L_{\mathrm{Wfb}} = 10\log\left(\frac{P_{\mathrm{fb}}}{P_0}\right) \quad [\mathrm{dB}] \tag{11}$$

where:

P_0 is the reference power (10^{-12} W)

8.7.4 Structure-borne power level

Calculate the structure-borne power level by the formula:

$$L_{\mathrm{Wsb}} = 10\log\left(\frac{P_{\mathrm{sb}}}{P_0}\right) \quad [\mathrm{dB}] \tag{12}$$

where:

P_0 is the reference power (10^{-12} W)

9 Information to be reported

The following vibro-acoustic information shall be compiled and recorded for measurements according to this document:

a) Level of total fluid-borne power;

b) Level of total structure-borne power;

c) 1/3-octave spectra of fluid-borne power level;

d) 1/3-octave spectra of structure-borne power level;

e) 1/3-octave spectra of coefficient of fluid-borne energy propagation;

f) 1/3-octave spectra of coefficient of structure-borne energy propagation.

NOTE The above is calculated from the Fast Fourier Transformation (FFT) analysis.

Annex A
(informative)
Bending wave number and intensity dimensional constant

Bending wave number k_{sb} and the associated dimensional constant K_{sb} needed to determine the structure-borne intensity by using Formula (4) both depend on the frequency. These quantities are obtained by solving the relation of dispersion for the fluid-filled pipe. For the vibration measurement pipe of prescribed dimensions (see 5.3) filled with water, both the bending wave number and the associated dimensional constant can be given in polynomial form:

$$k_{sb}(f) = \sum_{n=0}^{15} P_k(n) f^n \qquad \text{(A.1)}$$

$$K_{sb}(f) = \sum_{n=0}^{15} Q_k(n) f^n \qquad \text{(A.2)}$$

where:

k_{sb}	is the bending wave number in m^{-1}
$P_k(n)$	is the coefficient on nth order for wave number polynomial
K_{sb}	is the structure-borne intensity dimensional constant in Ws^4/m^3
$Q_k(n)$	is the coefficient on nth order for the associated dimensional constant polynomial
f	is the frequency in Hz

The coefficients $P_k(n)$ and $Q_k(n)$ are given in the Table A.1.

Table A.1 — Coefficients $P_k(n)$ and $Q_k(n)$

n	$P_k(n)$	$Q_k(n)$
0	$9{,}191\,531\,730\,933\,632 \times 10^{-1}$	$2{,}453\,630\,851\,250\,135 \times 10^{6}$
1	$7{,}644\,003\,204\,232\,786 \times 10^{-2}$	$-3{,}453\,686\,638\,310\,214 \times 10^{5}$
2	$-8{,}550\,458\,718\,746\,952 \times 10^{-4}$	$3{,}529\,880\,907\,313\,807 \times 10^{4}$
3	$9{,}395\,883\,345\,803\,304 \times 10^{-6}$	$6{,}500\,083\,821\,268\,914 \times 10^{2}$
4	$-7{,}592\,454\,346\,606\,851 \times 10^{-8}$	$-2{,}517\,623\,922\,139\,443 \times 10^{0}$
5	$4{,}435\,931\,238\,145\,724 \times 10^{-10}$	$1{,}137\,477\,695\,843\,318 \times 10^{-2}$
6	$-1{,}893\,892\,534\,428\,029 \times 10^{-12}$	$-4{,}263\,277\,267\,379\,334 \times 10^{-5}$
7	$5{,}979\,170\,403\,451\,006 \times 10^{-15}$	$1{,}243\,573\,041\,487\,822 \times 10^{-7}$
8	$-1{,}406\,556\,256\,150\,061 \times 10^{-17}$	$-2{,}774\,257\,279\,426\,475 \times 10^{-10}$
9	$2{,}469\,612\,247\,609\,014 \times 10^{-20}$	$4{,}689\,566\,527\,408\,795 \times 10^{-13}$
10	$-3{,}217\,980\,995\,719\,116 \times 10^{-23}$	$-5{,}939\,275\,339\,140\,709 \times 10^{-16}$
11	$3{,}064\,353\,525\,551\,454 \times 10^{-26}$	$5{,}532\,259\,814\,305\,975 \times 10^{-19}$
12	$-2{,}069\,860\,566\,521\,089 \times 10^{-29}$	$-3{,}671\,640\,122\,946\,185 \times 10^{-22}$
13	$9{,}386\,247\,482\,026\,814 \times 10^{-33}$	$1{,}641\,266\,003\,553\,832 \times 10^{-25}$
14	$-2{,}561\,150\,398\,477\,605 \times 10^{-36}$	$-4{,}425\,360\,224\,978\,495 \times 10^{-29}$
15	$3{,}176\,743\,706\,757\,041 \times 10^{-40}$	$5{,}434\,195\,752\,593\,468 \times 10^{-33}$

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