INTERNATIONAL STANDARD

ISO 20155

First edition
2017-08

Ships and marine technology — Test method of flow induced in-pipe noise source characteristics for a ship-used pump

Navires et technologie maritime — Méthode pour déterminer les caractéristiques des sources de bruit induites par l'écoulement dans les tuyaux d'une pompe de navire

Reference number
ISO 20155:2017(E)

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Foreword

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This document was prepared by Technical Committee ISO/TC 8, *Ships and marine technology*, Subcommittee SC 8, *Ship design*.

Introduction

In hydraulic fluid power systems of ships, power is transmitted through a liquid under pressure. Pumps are components that convert rotary mechanical power into hydraulic fluid power. During the process of converting mechanical power into hydraulic power, flow and pressure fluctuations and structure-borne vibrations are generated. These fluid-borne and structure-borne vibrations, which are generated primarily by the unsteady flow produced by the pump, are transmitted through the connected piping system.

The fluid-borne vibration generated by a pump is called pressure ripple or flow induced noise. For pumps used for coolant and drainage in ships, flow induced noise can be transmitted along the piping and radiated into the surrounding water area through a pipe mouth outboard the ship, which produces noise pollution and disturbs the environment including marine mammals.

The level of flow induced noise for a pump depends upon not only the characteristics of the pump itself, but also the circuit in which the pump is installed. Thus, the determination of flow induced noise by a pump is complicated by the interaction between the pump and the circuit. The directly measured data using hydrophones inserted in pipe reaches connecting the pump cannot reflect noise source characteristics of the pump. The method adopted to measure the flow induced noise of a pump should be such as to eliminate the interaction.

ISO 10767-1 and ISO 10767-2 provide the test methods for the positive displacement pump with the precision and simplified method, respectively, where the pump is treated as a single port acoustic source and its source characteristics expressed by two parameters of source strength as well as source impedance can be obtained. For other common pumps with two ports, the sound field between the inlet and outlet of a pump is inter-coupling, source characteristics cannot be fully expressed by two parameters, but expressed by up to six parameters, i.e. source pressures at the inlet and outlet of a pump and four elements in a 2 × 2 impedance matrix. There is a need to establish a new standard about a test method for noise source characteristics of a pump, based on two-port acoustic source model.

The source characteristics of flow induced noise are used for evaluating the hydrodynamic noise feature of the pump. The measured results can be compared for pumps of different types and manufacture. This will enable the pump designer to evaluate the effects of design modifications and help hydraulic system designers to avoid selecting pumps having high noise levels.

The method is based upon the application of plane wave transmission line theory to the analysis of noise propagation in hydraulic systems. By adopting a two-port model with noise source and evaluating the impedance characteristics of the pump using a secondary-source method, it is possible to obtain the source strength of the pump, independent of the circuit that the pump locates.

Ships and marine technology — Test method of flow induced in-pipe noise source characteristics for a ship-used pump

1 Scope

This document specifies a test method for determining flow induced in-pipe noise source characteristics of a ship-used pump as a two-port sound source in laboratory conditions by measuring acoustic pressures in the pipe reaches of inlet and outlet.

The test method is applicable to all types of centrifugal pumps with a diameter over 50 mm operating under steady conditions.

The suitable frequency range of the test method is about 10 Hz to 1 000 Hz, and the upper frequency is dependent on the inner diameter of the pipe, in which the plane acoustic wave propagates.

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 10767-1:2015, *Hydraulic fluid power — Determination of pressure ripple levels generated in systems and components — Part 1: Method for determining source flow ripple and source impedance of pumps*

IEC 60565, *Underwater acoustics — Hydrophones — Calibration in the frequency range 0,01 Hz to 1 MHz*

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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

3.1
two-port source
test object with inlet and outlet which are inter-coupling acoustically

3.2
passive characteristic
acoustic characteristic of a test object only acting as a transmission path, which can be indicated by different manners such as a transfer matrix, impedance matrix, scattering matrix, etc.

3.3
active characteristic
acoustic characteristic of a test object which provides acoustic energy into a piping system

Note 1 to entry: Depending on the adopted theoretical model, active characteristics can be represented by acoustic pressure source, volume velocity source, etc.

3.4
test section
pipe reaches which are used to fix the hydrophones, measuring the in-pipe noise from the acoustic source

3.5
static pressure in pipe
fluid pressure in pipe as fluid is in still, which is one of the parameters describing the working conditions of the test object

3.6
working flowrate
fluid volume or mass per unit time, which is one of the working parameters of the test object

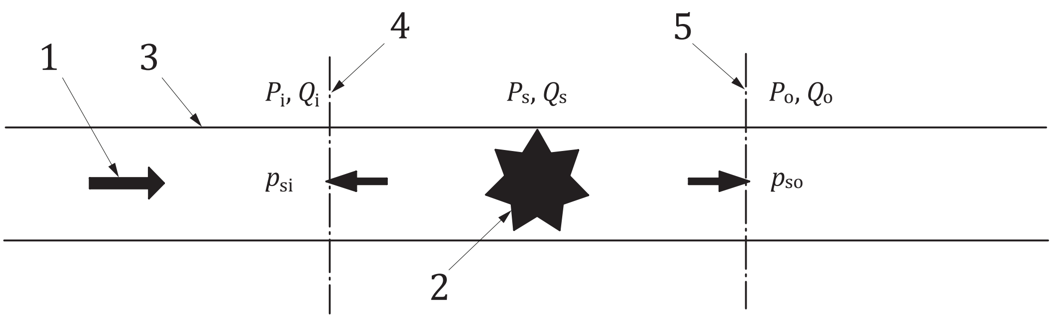
3.7
pressure drop/hydraulic loss
static pressure difference between the inlet and outlet as the fluid passes through the test object, which is a reference parameter for analysis use

3.8
foundation
platform built by ferroconcrete, used to install the experimental facility and test objects, including ground basis, guide rail for convenient mount of pipeline

4 Two-port source model and test method of source characteristic of pump

4.1 Two-port source model of a pump

It is assumed that only plane wave would transmit in the pipeline, and the noise source characteristic of a pump could be described by linear superposition of active and passive characteristic. Based on the electro-acoustic analogy and acoustic transmission line theory, there are three different models to characterize a two-port source, which can be called "Transmission model", "Impedance model" and "Scattering model". They are illustrated in Annex A.



Key
1 flow
2 source
3 pipe
4 inlet
5 outlet

Figure 1 — Two-port noise source model

Adopting the impedance model, the radiating sound from the inlet and outlet into pipe can be expressed by Formula (1):

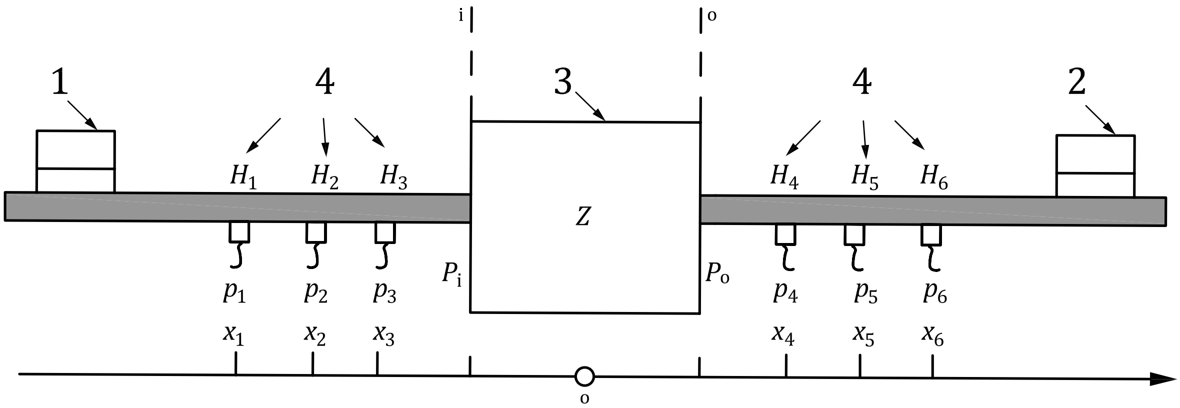
$$\begin{pmatrix} P_o \\ P_i \end{pmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{pmatrix} Q_o \\ Q_i \end{pmatrix} + \begin{pmatrix} P_{so} \\ P_{si} \end{pmatrix} = \boldsymbol{Z} \begin{pmatrix} Q_o \\ Q_i \end{pmatrix} + \begin{pmatrix} P_{so} \\ P_{si} \end{pmatrix} \tag{1}$$

where

P_s, Q_s	is the real sound source of a pump providing sound pressure and volumetric velocity into the inlet and outlet of the pump, while the connected pipes are unlimited or anechoic;
P_o, Q_o	is the sound pressure and volumetric velocity at the outlet of acoustic source, respectively;
P_i, Q_i	is the sound pressure and volumetric velocity at the inlet of acoustic source, respectively;
P_{so}, P_{si}	is the sound pressure source which indicate radiating sound from the inlet and outlet into pipe;
Z	is the impedance matrix, $Z = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}$.

4.2 Test methods for source characteristic parameters of the pump

Using the secondary-source method, turn on the secondary acoustic source on one side (inlet or outlet), get and register signals from the four hydrophones. Then, move it to another side and turn it on, register signals of the four hydrophones again. By this procedure, matrix parameter Z can be derived. Finally, turn off the source, active characteristic parameters p_s and q_s of the pump can be obtained utilizing the result of matrix parameter Z.



Key

1 secondary source 1
2 secondary source 2
3 test pump
4 hydrophones H_1 to H_6

Figure 2 — Sketch of dual-position acoustic source methods

In Figure 2, H_1 to H_6 are six hydrophones along the pipe mounted at positions x_1 to x_6, correspondingly.

The procedure for measuring source characteristics is given as follows.

a) Turn on the secondary acoustic source at the inlet for the following result:

$$\begin{pmatrix} P_o^{(1)} \\ P_i^{(1)} \end{pmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{pmatrix} Q_o^{(1)} \\ Q_i^{(1)} \end{pmatrix} \tag{2}$$

where superscript $^{(1)}$ indicates the corresponding quantities obtained by turning on the secondary sound source at the first time, and they can be obtained by means of calculation using formulae in Annex B, which correlate the quantities with the measured signals from hydrophones.

b) Turn on the secondary acoustic source at the outlet for the following result:

$$\begin{pmatrix} P_o^{(2)} \\ P_i^{(2)} \end{pmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{pmatrix} Q_o^{(2)} \\ Q_i^{(2)} \end{pmatrix} \tag{3}$$

where superscript $^{(2)}$ indicates the corresponding quantities obtained by turning on the secondary sound source at the second time.

c) Combine Formulae (2) and (3) and solve the equation system, the impedance matrix Z can be calculated.

$$\begin{pmatrix} P_o^{(1)} & P_o^{(2)} \\ P_i^{(1)} & P_i^{(2)} \end{pmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{pmatrix} Q_o^{(1)} & Q_o^{(2)} \\ Q_i^{(1)} & Q_i^{(2)} \end{pmatrix} \tag{4}$$

d) Turn off the secondary acoustic source, and let the measured pump operate under the needed conditions, the active source parameters, i.e. sound pressure source P_{so}, P_{si} can be obtained according to Formula (5).

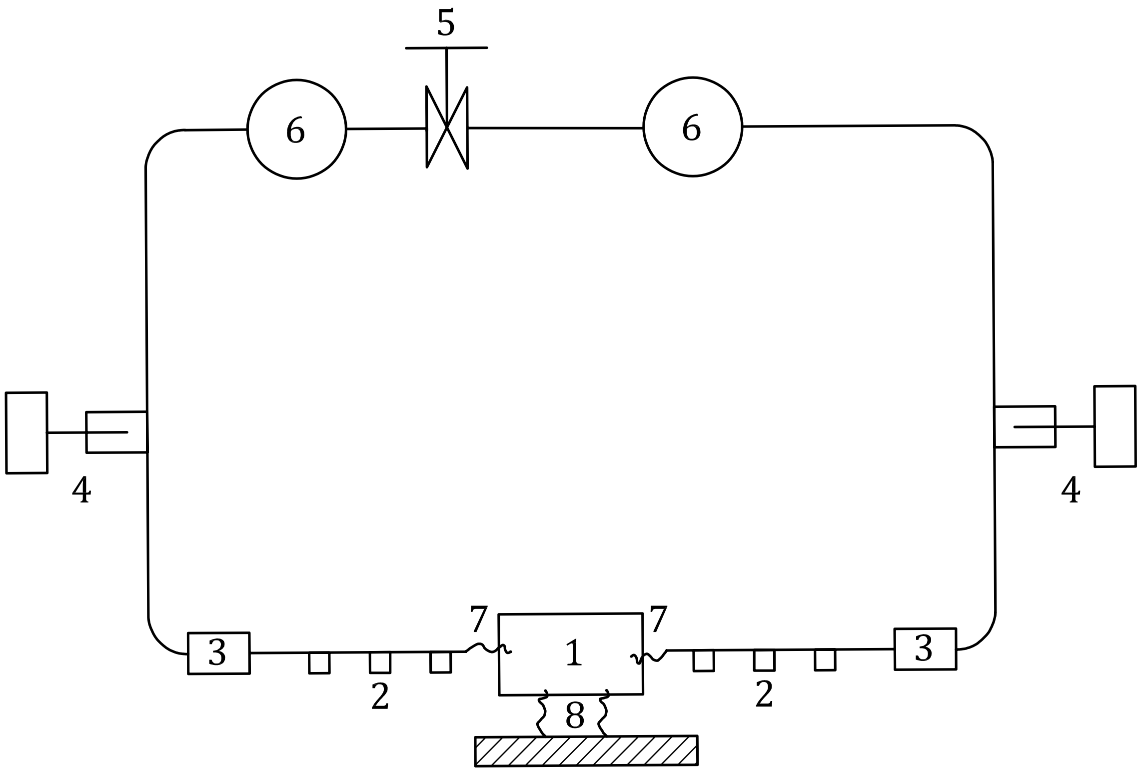
$$\begin{pmatrix} P_{so} \\ P_{si} \end{pmatrix} = \begin{pmatrix} P_o \\ P_i \end{pmatrix} - \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{pmatrix} Q_o \\ Q_i \end{pmatrix} \tag{5}$$

At the right side of Formula (5), P_o, P_i and Q_o, Q_i are obtained by calculation using the measured signals from hydrophones during pump operation.

5 Test rig

5.1 Test loop

Figure 3 shows the schematic of test circuit of flow induced in-pipe noise source characteristic of the pump.



Key

1 pump
2 hydrophone
3 vibration
4 secondary acoustic excitor
5 throttling valve
6 water tank
7 flexible insertion
8 vibroisolator
9 foundation

Figure 3 — Sketch of test circuit for measuring flow-noise source characteristic of the pump

In the schematic diagram, a water tank is used for separating sound waves from the inlet and outlet of pump. A throttling valve is used for flowrate adjustment and located between the water tanks for reducing the effect on source characteristic measurement of the pump. A secondary acoustic exciter can provide an external acoustic source for determination of passive features of the pump, and the vibration damper can suppress the vibration of the test section from the neighbouring pipe reaches. Hydrophones are mounted in test sections at the inlet and outlet of the pump for measuring the acoustic pressure in the pipeline.

5.2 Installation of test pump

The test pump should be installed as recommended by the manufacturer and mounted in such a manner that the response of the mounting-to-pump vibration is minimized.

In order to reduce vibration disturbance from the ground and the connected pipe, the pump should be installed on the foundation through vibration isolators and connected to the pipeline with flexible insertions. The isolators and flexible insertions should be chosen close to the actual conditions.

The prime mover and associated drive couplings shall not generate torsional vibration in the pump shaft. If necessary, the pump and the driving unit shall be isolated from each other to eliminate vibration generated by the prime mover.

5.3 Ground foundation and supporting structure

Ground foundation should be made of reinforced concrete and isolated to the surrounding ground in the laboratory such as foundations of other auxiliary equipment. A supporting structure of the pipeline is also required to be rigidly connecting the pipeline with the ground foundation.

5.4 Test-bed pipeline

The pipeline shall be composed of uniform, rigid, straight metal pipes at each port of the pump.

The inner diameters of the test pipeline at inlet and outlet should be equal to that of the inlet and outlet of the test pump respectively. In the case of the inequality of inner diameter between the test pump and pipeline, the adaptor connecting the pump ports to the pipe shall have an internal diameter which does not differ from the pipe diameter by more than 10 % at any point. Any such variations in internal diameter shall occur over a length not exceeding twice the internal diameter of the pipe. The adaptor shall be arranged in order to prevent the formation of air pockets in it.

The bending section in the pipeline of Figure 3 shall adopt bends with bending radii larger than twice the radii of the pipe to reduce hydrodynamic noise arising from the flow over it.

The total length of the uniform straight pipeline in front of the inlet flange of the test pump should be 10 times larger than pipe diameter.

5.5 Test section

Each of the two test sections as a straight pipe reach is fixed on the inlet and outlet of the test pump respectively, with the length more than 2 m, the inner diameters, *D*, equal to that of inlet and outlet pipe of the test pump. The test section should be fabricated with a tube of wall thickness greater than 5 % of the inner diameters, *D*. In the test section, two or three hydrophones with equal interval are fixed on the pipe. Each hydrophone is put in a plug mounted on the pipe. In order to reduce interference from turbulence over the inner wall of the pipe, the hydrophones shall be mounted such that their diaphragms are flush with the inner wall of the pipe to within ±0,5 mm. The sealing ring in the plug should be used between the hydrophone and plug body to prevent water leakage.

The distance between two or two of three hydrophones depends on the maximum frequency of the measurement frequency range and shall be given by Formula (6), to within 1 %:

$$x_2 - x_1 = \frac{\sqrt{B_{\text{eff}} \times 10^5 / \rho}}{(67 \times f_{0,\max})} \qquad (6)$$

where

$f_{0,\max}$ is the maximum frequency of the measurement frequency range, in hertz;

B_{eff} is the effective bulk modulus, in bars;

ρ is the density, in kilograms per cubic meter.

Meanwhile, in order to avoid turbulent fluctuation pressure from the pump impacting directly on hydrophone, the nearest hydrophone should be positioned at a distance larger than 3 to 5 times pipe inner diameter from the test pump.

5.6 Throttling valve

The throttling valve should meet the need of flowrate adjustment. From the point of acoustic measurement, it should have a low noise level and no cavitation should appear under the test working conditions.

