SLOVENSKI STANDARD
SIST EN ISO 11688-2:2001

01-september-2001

Akustika - Priporočila za konstruiranje tihih strojev in naprav - 2. del: Fizikalne osnove za načrtovanje (ISO/TR 11688-2:1998)

Acoustics - Recommended practice for the design of low-noise machinery and equipment - Part 2: Introduction to the physics of low-noise design (ISO/TR 11688-2:1998)

Akustik - Richtlinien für die Gestaltung lärmarmer Maschinen und Geräte - Teil 2: Einführung in die Physik der Lärmminderung durch konstruktive Maßnahmen (ISO/TR 11688-2:1998)

Acoustique - Pratique recommandée pour la conception de machines et équipements a bruit réduit - Partie 2: Introduction a la physique de la conception a bruit réduit (ISO/TR 11688-2:1998)

Ta slovenski standard je istoveten z: **EN ISO 11688-2:2000**

ICS:

17.140.20	Emisija hrupa naprav in opreme	Noise emitted by machines and equipment
21.020	Značilnosti in načrtovanje strojev, aparatov, opreme	Characteristics and design of machines, apparatus, equipment

SIST EN ISO 11688-2:2001 **en**

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN ISO 11688-2

December 2000

ICS 17.140.20; 21.020

English version

Acoustics - Recommended practice for the design of low-noise machinery and equipment - Part 2: Introduction to the physics of low-noise design (ISO/TR 11688-2:1998)

Acoustique - Pratique recommandée pour la conception de machines et équipements à bruit réduit - Partie 2: Introduction à la physique de la conception à bruit réduit (ISO/TR 11688-2:1998)

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This European Standard was approved by CEN on 17 September 1999.

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Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN ISO 11688-2:2000 E

Foreword

The text of the International Standard from Technical Committee ISO/TC 43 "Acoustics" of the International Organization for Standardization (ISO) has been taken over as an European Standard by Technical Committee CEN/TC 211 "Akustik", the secretariat of which is held by DS.

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publication of an identical text or by endorsement, at the latest by 2001, and conflicting national standards shall be withdrawn at the latest by June 2001.

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Endorsement notice

The text of the International Standard ISO/TR 11688-2:1998 has been approved by CEN as a European Standard without any modification.

TECHNICAL REPORT

ISO/TR 11688-2

First edition
1998-09-01

Acoustics — Recommended practice for the design of low-noise machinery and equipment —

Part 2:
Introduction to the physics of low-noise design

Acoustique — Pratique recommandée pour la conception de machines et équipements à bruit réduit —

Partie 2: Introduction à la physique de la conception à bruit réduit

Reference number
ISO/TR 11688-2:1998(E)

Contents

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Printed in Switzerland

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 organisations, 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 main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example)

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 11688-2, which is a Technical Report of type 3, was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

ISO 11688 consists of the following parts, under the general title *Acoustics — Recommended practice for the design of low-noise machinery and equipment*:

— *Part 1: Planning*

— *Part 2: Introduction to the physics of low-noise design*

Introduction

The objective of this part of ISO/TR 11688 is noise reduction in existing machinery and noise control at the design stage of new machinery.

It is important that non-acoustic engineers are engaged in noise control practice. It is of great importance for these engineers to have a basic knowledge of noise generation and propagation characteristics and to understand the principles of noise control measures.

Acoustics — Recommended practice for the design of low-noise machinery and equipment —

Part 2:
Introduction to the physics of low-noise design

1 Scope

This part of ISO/TR 11688 provides the physical background for the low-noise design rules and examples given in ISO/TR 11688-1[1)] and supports the use of extensive special literature.

It is intended for use by designers of machinery and equipment as well as users and/or buyers of machines and authorities in the field of legislation, supervision or inspection.

Equations given in this Technical Report will improve the general understanding of noise control. In many cases they allow a comparison of different versions of design, but they are not useful for the prediction of absolute noise emission values.

Information on internal sound sources, transmission paths and sound radiating parts of a machine is the basis for noise control in machines. Therefore measurement methods and computational methods suitable to obtain this information are described in clauses 7 and 8 and annex A.

2 References

See ISO/TR 11688-1 and the bibliography.

3 Definitions

See ISO/TR 11688-1 and annex A.

4 Acoustical modelling

In order to facilitate the understanding of complex sound generation and propagation mechanisms in machinery and equipment or vehicles (the latter are also called "machines" in this part of ISO/TR 11688), it is necessary to create simple acoustical models. The models provide a basis for noise control measures at the design stage.

[1)] ISO/TR 11688-1:1995, *Acoustics — Recommended practice for the design of low-noise machinery and equipment — Part 1: Planning.*

A universal approach is to distinguish between

— internal sources;

— transmission paths inside the machine;

— radiation from its boundaries.

The internal sources and the transmission paths can each be assigned to three categories according to the media used:

— airborne;

— liquid-borne;

— structure-borne.

Radiation is considered for air only.

Figures 1 and 2 serve to illustrate the principle of acoustical modelling. Figure 1 shows a simplified machine consisting of an electric motor and a housing with an opening in it.

The motor is the only internal source. It generates airborne and structure-borne sound.

There are three internal transmission paths:

— through the air inside the housing to the opening;

— through the air inside the housing to the walls of the housing;

— through the fastenings to the walls of the housing.

Radiation occurs from the opening and from the walls of the housing.

Figure 2 illustrates this in a block diagram.

The total sound power emitted from the machine is the sum of the three contributions.

A systematic approach starts with an assessment of the relative importance of these contributions. The next step is examining the blocks in Figure 2 looking for possibilities to reduce source strength, transmission and/or radiation (see also following clauses). This should be done in relation to the various aspects of the design process (see ISO/TR 11688-1:1995, Figure 1).

5 Control of airborne and liquid-borne noise

The basic principles of generation, transmission and radiation of sound in air (or other gases) and liquids are basically identical and are therefore considered together in this clause. There is only one important exception: cavitation. Occurring in liquids only, this phenomenon is considered separately in 5.1.3.

5.1 Generation of fluid-dynamic noise

Important noise-generating phenomena in gases and liquids are turbulence, pulsation and shock. Fluid-dynamic processes generate noise if flow rate and pressure vary over time in a limited volume of a liquid or a gas, for example in a turbulent flow. This leads to the transmission of sound from the disturbed volume of the fluid to the surrounding medium. A classic example of this is the escape of compressed air from a nozzle.

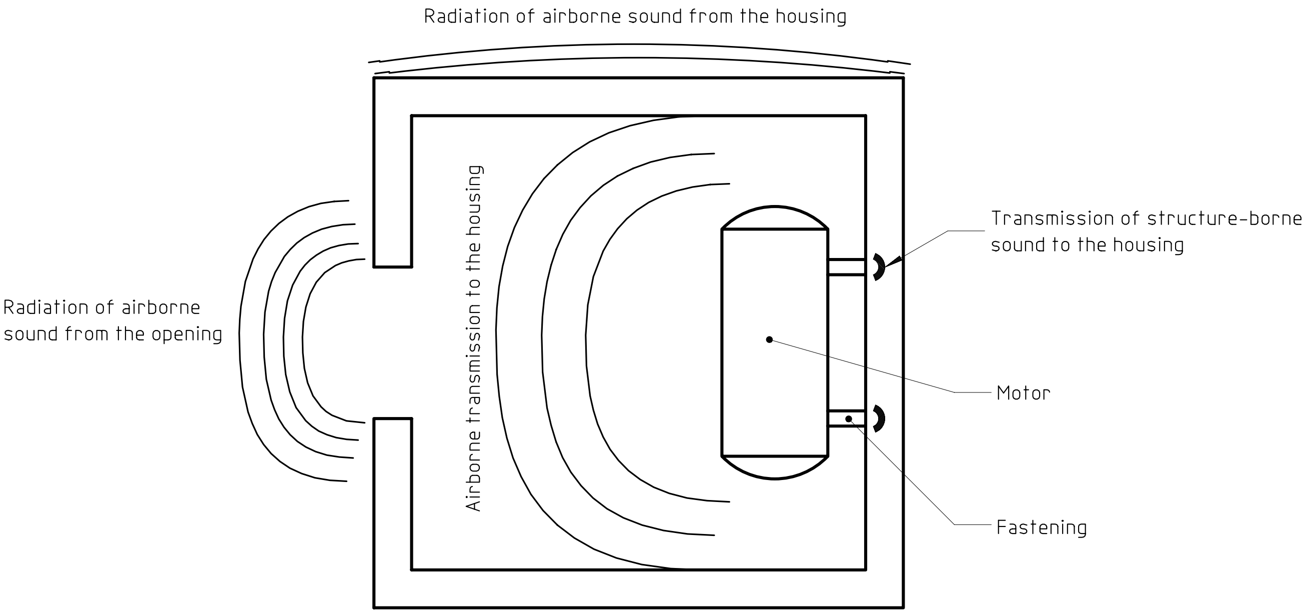


Figure 1 — Simplified machine for the illustration of acoustical modelling

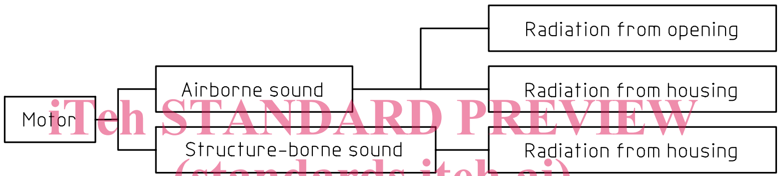


Figure 2 — Block diagram for the illustration of generation, transmission and radiation of sound in the "machine" of Figure 1

Mechanisms of fluid-dynamic sound generation can be related to properties of elementary sound sources with known characteristics:

— monopoles;

— dipoles;

— quadrupoles.

5.1.1 Elementary model sources

A <u>monopole</u> source is an in-phase volume change, such as a pulsating volume of any shape or a piston in a large rigid surface. In the far field, monopoles have a spherical radiation pattern. The sound radiated from a monopole source can be reduced by reducing the temporal variation in the volume flow rate.

EXAMPLE 1: Outlets of internal combustion engines, rotary piston fans, multi-cell compressors, piston pumps, piston compressors, flares.

A <u>dipole</u> source arises as a result of external time-variable forces acting on a fluid without volume change, such as in an oscillating rigid body of any shape. The dipole source can be replaced by two monopole sources of equal strength and opposite phase situated very closely together. The far-field directivity pattern of a dipole is shown in Table 1. Radiation from a dipole can be reduced by reducing the temporal variation of the forces acting on the fluid.

EXAMPLE 2: Vibrating rigid parts of machinery, parts of machinery running out of balance, ducts, propellers and fans.

A <u>quadrupole</u> source can be represented by a time-variable deformation of a body without change of its volume or position. It can be replaced by two dipole sources of equal strength and opposite phase situated very closely together. The far-field directivity pattern is shown in Table 1. Radiation from a quadrupole is reduced when the time-variable deformation is reduced.

EXAMPLE 3: Free turbulent flow as in safety valves, compressed-air nozzles, pipe fittings.

Most sound sources encountered in machinery contain aspects of more than one elementary source.

NOTE Because of the stochastic nature of turbulence the sound spectrum is broad-band. An example is the turbulent flow in the mixing zone of a free jet, particularly for Mach numbers $Ma > 0{,}8$. The definition of the Mach number is:

$$Ma = \frac{u}{c} \qquad (1)$$

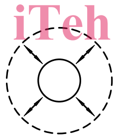
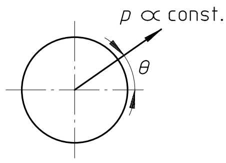
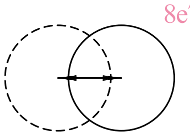
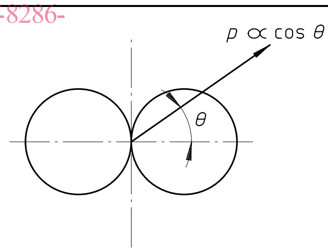
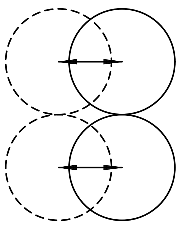
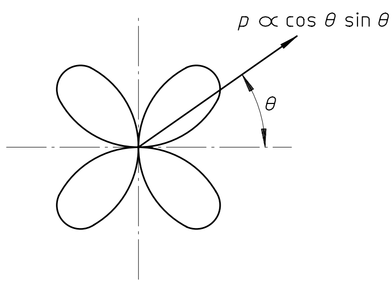
where

u is the flow velocity;

c is the speed of sound.

Table 1 summarizes and illustrates the information on the properties of the elementary sources.

Table 1 — Properties of elementary model sources

Type of source	Schematic illustration	Example(s)	Far-field directivity
<u>Monopole</u> "Breathing" sphere		Siren, piston compressor or pump, exhaust of internal combustion engine, cavitation phenomena, compressed air engine, gas burner	
<u>Dipole</u> Oscillating sphere		Slow machines (axial and centrifugal fans), obstacles in the flow (flow separation), ventilating or air-conditioning systems, ducts with flow	
<u>Quadrupole</u> Two oscillating spheres with an opposite phaseshift (two dipole sources)		Turbulent flow (mixing zone of a free jet), compressed-air nozzles, steam jet equipment, safety valves	

5.1.2 Influence of main parameters

The sound power radiated by aerodynamic sound sources (e.g. the elementary source models monopole, dipole, quadrupole) can be approximated by (see reference [17]):

$$W = \rho D^2 u^3 \left(\frac{u}{c}\right)^k = \rho D^2 u^3 (Ma)^k \qquad (2)$$

where

ρ is the density of the liquid,

D is the characteristic dimension of the elementary source,

u is the flow velocity,

k the exponent of the Mach number, which depends on the type of elementary source.

NOTE 1 The following is typical:

— $k = 1$ for a monopole source;

— $k = 3$ for a dipole source;

— $k = 5$ for a quadrupole source.

NOTE 2 Stüber and Heckl [18] have shown that for a three-dimensional sound field and three-dimensional sound propagation the following relationship applies:

$$k = (n - 3) + (2e - 1) \quad (3)$$

where

n is the dimension of the flow field and

e is the parameter of elementary sources (monopole: $e = 1$, dipole: $e = 2$, quadrupole: $e = 3$).

Table 2 shows a summary of the influence of flow velocity and flow field dimension on sound power emission.

Table 2 — Summary of functional relationship between the sound power, W, flow velocity, u, and dimension of flow field, n (see reference [18])

	Dimension n of flow field		
	$n = 1$	$n = 2$	$n = 3$
Mass flow fluctuation (monopole)	$W \sim \rho a u^2$	$W \sim \rho u^3$	$W \sim \frac{\rho}{\alpha} u^4$
Force fluctuation (dipole)	$W \sim \frac{\rho}{\alpha} u^4$	$W \sim \frac{\rho}{\alpha^2} u^5$	$W \sim \frac{\rho}{\alpha^3} u^6$
Turbulence (quadrupole)	$W \sim \frac{\rho}{\alpha^3} u^6$	$W \sim \frac{\rho}{\alpha^4} u^7$	$W \sim \frac{\rho}{\alpha^5} u^8$

Since the sound power of a fluid-dynamic noise source (in a three-dimensional flow field) increases in proportion to the fourth power for a monopole source, the sixth power for a dipole source and the eighth power for a quadrupole source, a reduction in flow velocity leads to a considerable reduction of the sound energy emitted. For machines with rotors, the demand for lower flow velocities also means that lower rotational speeds, i.e. lower peripheral velocities, are required.

Figure 3 shows how the sound power level of a source varies along with a variation of the flow rate. If a characteristic fluid-mechanical value (e.g. mass flow rate, volume flow rate, mechanical power consumption) is to be conserved, a reduction of flow velocity must be compensated by an increase of the characteristic dimension D.

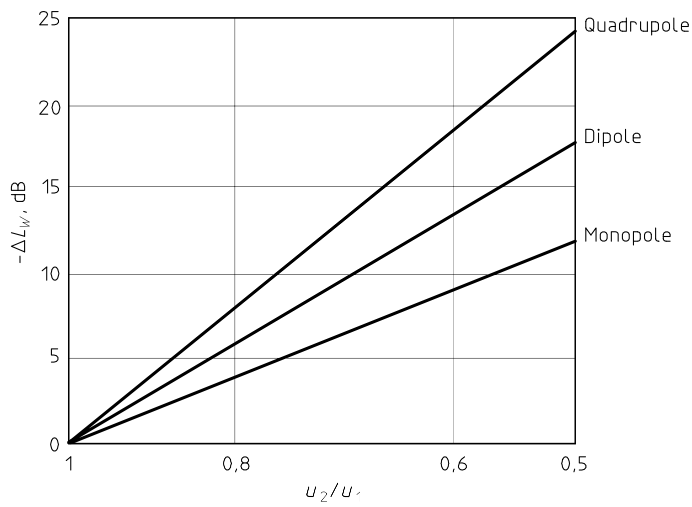
Examples of the characteristic dimension are

— duct diameter for duct flow,

— impeller diameter in flow machines,

— smallest dimension of obstacles in flow,

— diameter of inlet or outlet nozzle.



u_1 = given flow rate; u_2 = reduced flow rate

Figure 3 — Reduction of sound emission by reduction of flow rate
(for three-dimensional sound propagation)

For a simple prediction or estimation of the sound power W of an aeroacoustic sound source mechanism, the acoustic efficiency is an important value:

$$\eta = \frac{W}{W_{\text{mech}}} \tag{4}$$

where W_{mech} is the mechanical or aerodynamic power of the flow.

An empirical estimation for the sound power level is

$$L_W = 120\ \text{dB} + 10\ \lg \eta \frac{W_{\text{mech}}}{W_0}\ \text{dB} \tag{5}$$

where W_0 = 1 W.

Examples of acoustic efficiencies in aeroacoustics are summarized in Table 3.

Theoretical methods of high accuracy for predicting or estimating the sound power level or the sound power spectra of fluid-borne sound are not generally available. Equation (2) can be written in a logarithmic form:

$$L_W = L_{W\text{sp}} + 20\ \lg \frac{D}{D_0}\ \text{dB} + k \cdot 10\ \lg Ma\ \text{dB} \tag{6}$$

If the specific sound power level $L_{W_{\text{sp}}}$ is known, acoustical data measured for certain configurations can be scaled using similarity laws, to apply to other configurations with different geometry, dimensions, flow velocities, static pressure levels or flowing media.

For the conversion of spectra, a distinction must be made between broad band and tonal components. The frequency of tonal noise is to be normalized with the Strouhal number St

$$St = \frac{fD}{u} \tag{7}$$

Table 3 — Typical values of the acoustic efficiency

Aeroacoustic sound source	Type of elementary source	Acoustic efficiency η
Piston compressor (radiation in long duct system)	monopole	$\eta = \frac{p'}{\Delta p}$ *)
Siren	monopole	1×10^{-1}
Trumpet	dipole	1×10^{-2}
Propeller aircraft	dipole	1×10^{-3}
Outlet flow (subsonic flow $Ma < 1$)	mixed	$1 \times 10^{-4} Ma^5$
Diesel engine (outlet flow noise)	mixed	1×10^{-4}
Gas turbine	mixed	1×10^{-5}
Flow machine (at design point)	dipole	1×10^{-6}
Free turbulent jet	quadrupole	$1 \times 10^{-4} Ma^5$
Propeller of a ship with cavitation	monopole	1×10^{-7}
*) p is the maximum value of variable pressure, Δp is the pressure difference.		

5.1.3 Cavitation

Cavitation is a special effect occurring exclusively in liquids. Where local pressure drops below the vapour pressure, cavitation will occur in flowing liquids. Bubbles are generated, which will collapse in a region of higher pressure. This is illustrated in Figure 4. In a flowing liquid the pressure is determined by the Bernoulli equation

$$\frac{u^2}{2} + \frac{p}{\rho} + gz = \text{const} \qquad (8)$$

where

u is the flow velocity

p is the static pressure

ρ is the density of the liquid

g 9,81 m/s^2

z is the height of liquid on top of the region of interest

NOTE $p = \rho gz$.

Equation (8) will allow the determination of low pressure regions where cavitation can occur. When entering a region where the pressure exceeds the vapour pressure, the bubbles implode.