BS EN 62458:2011

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Sound system equipment — Electroacoustic transducers — Measurement of large signal parameters

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National foreword

This British Standard is the UK implementation of EN 62458:2011. It is identical to IEC 62458:2010.

The UK participation in its preparation was entrusted to Technical Committee EPL/100, Audio, video and multimedia systems and equipment.

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

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English version

Sound system equipment - Electroacoustic transducers - Measurement of large signal parameters
(IEC 62458:2010)

Equipements pour systèmes électroacoustiques - Transducteurs électroacoustiques - Mesure des paramètres en grand signal
(CEI 62458:2010)

Elektroakustische Geräte - Elektroakustische Wandler - Messung von Großsignal-Parametern
(IEC 62458:2010)

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European Committee for Electrotechnical Standardization
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Foreword

The text of document 100/1624/FDIS, future edition 1 of IEC 62458, prepared by IEC/TC 100, Audio, video and multimedia systems and equipment, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 62458 on 2011-01-02.

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The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2011-10-02
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2014-01-02

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 62458:2010 was approved by CENELEC as a European Standard without any modification.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application 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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60268-1	-	Sound system equipment - Part 1: General	HD 483.1 S2	-
IEC 60268-5 A1	2003 2007	Sound system equipment - Part 5: Loudspeakers	EN 60268-5 A1	2003 2009

CONTENTS

INTRODUCTION

Electro-mechanical-acoustical transducers such as loudspeaker drive units, loudspeaker systems, headphones, micro-speakers, shakers, and other actuators behave in a nonlinear manner at higher amplitudes. This limits the acoustical output and generates nonlinear signal distortion. Linear models fail in describing the large signal behaviour of such transducers and extended models have been developed which consider dominant nonlinearities in the motor and suspension. The free parameters of the large signal model have to be measured on the particular transducer by using static or dynamic methods. The large signal parameters show the physical cause of the signal distortion directly and are very important for the objective assessment of sound quality and failure diagnostics in development and manufacturing. Furthermore, the model and parameters identified for a particular transducer are the basis for predicting the maximum output and signal distortion for any input signal. The close relationship between causes and symptoms simplifies the interpretation of the harmonic and intermodulation distortion measured according to IEC 60268-5. Large signal parameters are valuable input data for the synthesis of loudspeaker systems and the development of electrical control systems dedicated to loudspeakers.

SOUND SYSTEM EQUIPMENT – ELECTROACOUSTICAL TRANSDUCERS – MEASUREMENT OF LARGE SIGNAL PARAMETERS

1 Scope

This International Standard applies to transducers such as loudspeaker drive units, loudspeaker systems, headphones, micro-speakers, shakers and other actuators using either an electro-dynamical or electro-magnetic motor coupled with a mechanical suspension. The large signal behaviour of the transducer is modelled by a lumped parameter model considering dominant nonlinearities such as force factor, stiffness and inductance as shown in Figure 1. The standard defines the basic terms and parameters of the model, the methods of measurements and the way the results should be reported.

2 Normative references

The following referenced documents are indispensable for the application 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.

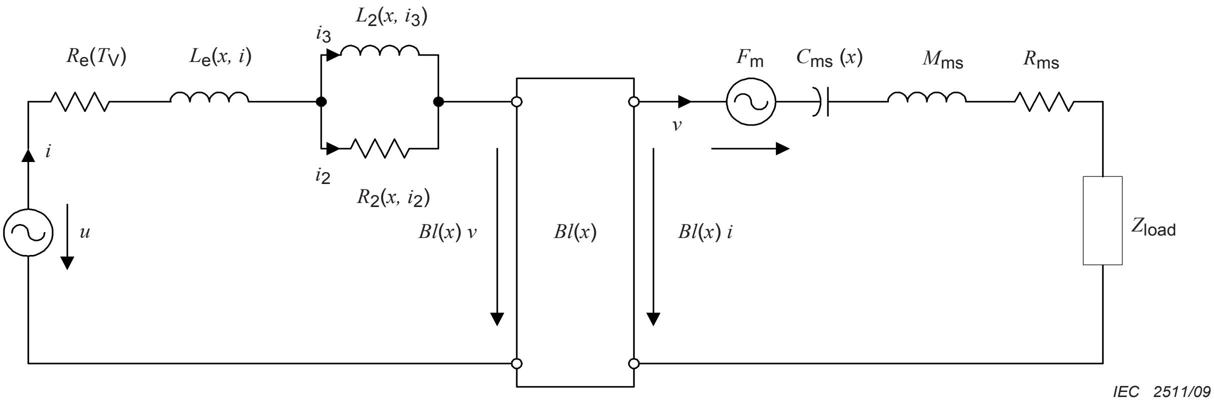
IEC 60268-1, *Sound system equipment – Part 1: General*

IEC 60268-5:2003, *Sound system equipment – Part 5: Loudspeakers*
Amendment 1 (2007)

3 Terms and definitions

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

3.1
electro-mechanical equivalent circuit
electrical circuit of an electro-dynamical transducer, as shown in Figure 1



NOTE 1 This Figure shows an example of a lumped parameter model of an electro-dynamical transducer considering the dominant nonlinearities.

NOTE 2 Other equivalent circuits can be applied. Contrary to the results of linear modelling some parameters of the lumped elements are not constant but depend on instantaneous state variables (such as displacement x, velocity v, current i).

Figure 1 – Electro-dynamical transducer

3.2
input current and voltage
i, u
electrical state variables at the terminals of the transducer

3.3 displacement
x
deflection of the voice coil from the rest position

3.4
velocity
v
time derivative of displacement x

3.5
d.c. resistance
$\boldsymbol{R_e}$
electrical impedance $Z_e(s)$ at very low frequencies where the effect of the back EMF can be neglected

NOTE Electrical impedance can be used for measuring the d.c. resistance R_e of the voice coil. The d.c. resistance R_e depends on the mean voice coil temperature T_V.

3.6
nonlinear inductance and losses
nonlinear elements to model the effect of the magnetic a.c. field, the losses in the magnetic material, and the losses caused by eddy currents where the equivalent circuit in Figure 1 uses the LR-2 model comprising the inductance $L_e(x, i)$, the inductance $L_2(x, i_2)$ and additional resistance $R_2(x, i_3)$

3.7
nonlinear force factor
$\boldsymbol{Bl(x)}$
dependency of instantaneous force factor $Bl(x)$ on voice coil displacement x defined by the integral of magnetic flux density B versus the voice-coil conductor of length l

NOTE The product of force factor $Bl(x)$ and velocity v is the back EMF generated on the electrical side in an equivalent circuit as shown in Figure 1. The product of force factor $Bl(x)$ and input current i gives the electro-dynamical driving force of the mechanical system.

3.8
reluctance force
$\boldsymbol{F_m}$
additional electro-magnetic driving force caused by the displacement varying inductances $L_e(x, i)$ and $L_2(x, i_2)$

3.9
stiffness, $\boldsymbol{K_{ms}(x)}$, of the suspension
ratio between the instantaneous restoring force $F(x)$ and the displacement x as given by

$$K_{ms}(x) = \frac{F(x)}{x} \quad (1)$$

NOTE The nonlinear compliance $C_{ms}(x) = 1/K_{ms}(x)$ is the reciprocal quantity of the mechanical stiffness.

3.10
mechanical mass
M_{ms}
total moving mass including the mass of the moving assembly and the reactive part of the air load on both sides of the diaphragm

3.11
mechanical resistance
R_{ms}
non-electrical losses of the driver, due to suspension, turbulences and radiation

3.12
mechanical impedance
Z_{load}
mechanical impedance which may represent any additional load caused by mechanical elements (cone, panel) or acoustical elements (such as a vented enclosure or horn)

4 Test signals

4.1 General

The measurement of the large signal parameters requires an electrical, mechanical or acoustical stimulus. Depending on the method used for the measurement of the large signal parameters different kind of test signals are used as stimulus for the excitation of the transducer. Since the loudspeaker behaves as a time-varying system the stimulus may cause a permanent or temporary change of the loudspeaker properties. Thus, the properties of the stimulus (spectral bandwidth, crest factor, proability density function) shall be statet. The same stimulus should be used if the numerical values of the results should be compared from two measurements.

4.2 Large d.c. signal

A constant d.c. voltage or d.c current of defined magnitude and sufficient duration is supplied to the electrical terminals to measure the steady-state response of the transducer. If the transducer is mounted in a sealed enclosure a difference between the static air pressures inside and outside the enclosure may be used as d.c. stimulus.

4.3 Large d.c. signal and small a.c. signal

A constant d.c. signal of defined magnitude and sufficient duration (see 4.2) superimposed with a small a.c. signal is used as stimulus. The a.c. signal (such as noise, sinusoidal sweep, impulsive test signals) should have sufficient bandwidth to identify all parameters of the loudspeaker model.

4.4 Broadband noise signal

One of the noise signals defined in IEC 60268-1 or any other noise having sufficient bandwidth and amplitude may be used as stimulus. The crest factor of the noise should be less than 4 to reduce clipping in the amplifier.

4.5 Music

Ordinary music, speech of sufficient bandwidth and amplitude may be used as a stimulus.

NOTE The dynamic methods need a stimulus which provides persistent excitation of the loudspeaker to identify the parameters correctly. The stimulus should have enough spectral components at least one octave below resonance frequency f_s and one decade above f_s.

5 Mounting condition

5.1 Drive units

The driver unit may be mounted

a) in free air without a baffle or enclosure,

b) in a standard baffle according to 11.1 of IEC 60268-5,

c) in half-space free field according to 5.2 of IEC 60268-5,

d) in the standard measuring enclosure (type A or type B) according to 11.2 of IEC 60268-5, or another, specified enclosure,

e) in vacuum,

f) other configuration defined in the presentation of the results.

The acoustic loading depends upon the mounting arrangement, which shall be clearly described in the presentation of the results.

During the measurement the transducer should be firmly clamped to suppress additional mechanical resonances close to the resonance frequency f_S. A vertical position of the transducer (cone displacement in horizontal direction) is recommended to avoid any bias due the weight of the moving assembly.

Drive units for horn loaded loudspeakers, headphones, micro-speakers and microphones should preferably be measured in a vacuum to reduce the acoustic load, suppress additional acoustic resonances, and to avoid nonlinear damping due to turbulent air flow.

5.2 Loudspeaker systems

Loudspeaker systems are measured under conditions which correspond with the intended use.

6 Climatic conditions

The measurements should be made at an ambient temperature 15°C to 35°C, preferably at 20°C, relative humidity 25 % to 75 %, air pressure 86 kPa to 106 kPa as specified in IEC 60268-1 to avoid any influence of temperature and humidity that may affect the properties of the drive unit suspensions.

7 Acoustical environment

The measurement room shall be large enough that the influence of the acoustical environment on the mechanical vibration of the transducer is negligible.

If the measurement of the large signal parameters is based on sound pressure output it is recommended to place the measuring microphone in the near field of the transducer. It is recommended to use a method that measures electrical or mechanical signals only, which is thus immune to unwanted acoustic noise.

8 Preconditioning

The loudspeaker should be preconditioned according to Clause 12 of IEC 60268-5. A temporary voice coil offset caused by storing the transducer for some time in the horizontal position can be removed by operating the transducer for at least 5 min in the vertical position before performing the regular measurement.

9 Time-varying properties of the loudspeaker

The stimulus provided to the electrical input of the loudspeaker may cause a heating of the voice coil and may also change the properties of the suspension during measurement. Thus, the electrical resistance of the coil should be measured during measurement and considered in the calculation of the loudspeaker parameters (e.g. electrical loss factor Q_{es}).

10 Methods of measurement

10.1 General

The following methods may be used for the measurement of the large signal parameters. The method used should be stated together with the results.

10.2 Static or quasi-static method

10.2.1 General

This technique determines the non-linear parameters of the transducer by using a d.c. signal with magnitude u_i (usually voltage) as stimulus. After reaching steady state relevant state variables (d.c. displacement x_i, d.c. force F_i) are measured and the parameter value (such as $K(x_i) = F_i/x_i$) is calculated. After changing the magnitude of the d.c. signal the measurement is repeated at further working points x_i with $i = 1, \ldots, N$ to measure the non-linear parameters within the working range $-x_{peak} < x_i < x_{peak}$ with sufficient resolution.

Due to the visco-elastic behaviour of the suspension material, the settling time required to reach steady state may exceed several seconds and a static method is very time consuming. In a quasi-static method the state variables are measured before steady state is reached and the settling time used should be stated.

Creep and other visco-elastic properties of the suspension cause significant discrepancies between the stiffness $K(x)$ measured statically by using a d.c. signal and the stiffness $K_{ms}(x)$ measured dynamically by using an broadband noise signal.

The d.c. signal of the static and quasi-static methods cannot be used for the measurement of the nonlinear voice coil inductance $L_e(x, i)$. Figure 2 shows a setup for static and quasi-static measurement of large signal parameters.

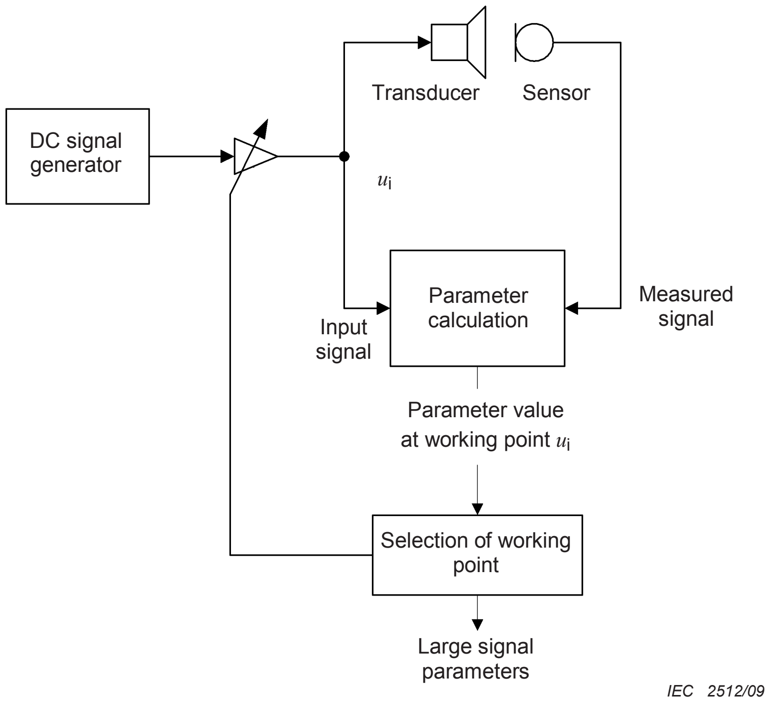


Figure 2 –Static and quasi-static measurement setup

10.2.2 Procedure

Proceed as follows.

a) According to the limits of working range $-x_{peak} < x_i < x_{peak}$ investigated and the resolution required, the number of measurements N is determined, a starting voltage u_{start} is selected and the incremental voltage u_{step} is defined.

b) The first working point i = 1 is initialized.

c) The transducer is excited by a d.c. signal voltage $u_i = u_{start} + i \times u_{step}$.

d) At the working point, i, the displacement, x_i, and other relevant state variables (such as force F_i) are measured after the transducer has reached steady state or a defined settling time T has passed.

e) The nonlinear parameter (for example, $K(x_i) = F_i/x_i$) is calculated.

f) The next working point $i = i + 1$ is selected and previous steps 1 to 5 are repeated until $i > N$.

g) The parameter values are interpolated between the working points x_i with $i = 1, \ldots, N$ or the coefficients of the power series expansion (such as Equation (3)) are calculated.

10.3 Point-by-point dynamic method

10.3.1 General

This technique determines the non-linear parameters of the transducer with a d.c. signal, u_i (such as d.c. voltage or a constant air pressure), superimposed with a small a.c. signal, u_{ac}, as stimulus. After reaching the steady state, the relevant state variables (d.c. displacement x_i and the amplitudes of the a.c. force F_{ac} and a.c. displacement x_{ac}) are measured and the parameter value (such as the incremental stiffness $K_{inc}(x_i) = F_{ac}/x_{ac}$) is calculated. After changing the magnitude of the d.c. part of the stimulus the measurement is repeated at further working points x_i with $i = 1, \ldots, N,$ to measure the non-linear parameters within the working range $-x_{peak} < x_i < x_{peak}$ with sufficient resolution.

The amplitude u_{ac} of the a.c. stimulus is sufficiently small to ensure that the transducer behaves linearly ($K(x_i + x_{ac})$ ≈ constant, $Bl(x_i + x_{ac})$ ≈ constant and $L_e(x_i + x_{ac})$ ≈ constant) and a linear loudspeaker model can be applied.

Whereas some small signal parameters (force factor $Bl(x_i)$ and inductance $L_e(x_i)$) are identical to the large signal parameters measured by other methods, this technique provides the incremental stiffness, $K_{inc}(x_i)$, which can only be transformed into the regular stiffness by integration

$$K(x) = \frac{1}{x}\int_0^x K_{inc}(x)\mathrm{d}x \tag{2}$$

Due to the visco-elastic behaviour of the suspension material, there are significant differences between the stiffness $K(x)$ measured by the point-by-point method using a d.c. signal and the stiffness Kms(x) measured dynamically with a program like an a.c. signal. Figure 3 shows a setup for point-by-point dynamic measurement of large signal parameters.

10.3.2 Test equipment

The stimulus comprising a d.c part and an a.c. part can be produced by using a generator with a d.c. offset and a d.c.-coupled power amplifier. However, providing the d.c. part via the electrical input produces significant heating of the voice coil at high amplitudes. Alternatively, the transducer may be mounted in a sealed box, and the voice coil position may be varied by changing the d.c. air pressure inside the box.

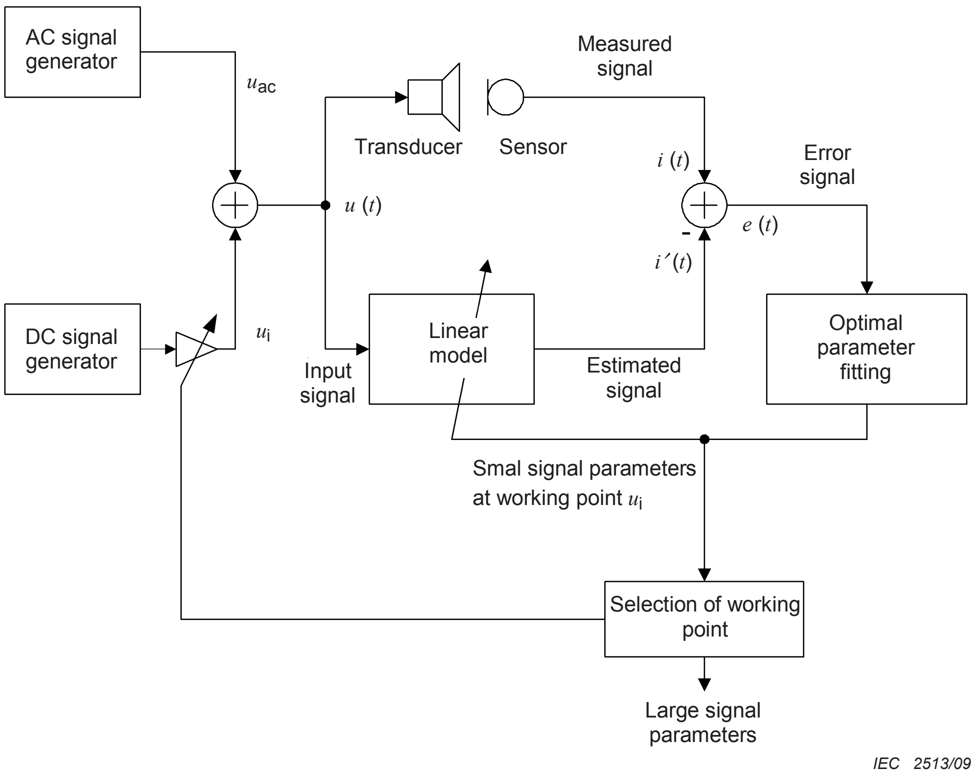


Figure 3 – Setup for measurement of large signal parameters by using the point-by-point dynamic method

10.3.3 Procedure

According to the limits of working range $-x_{peak} < x_i < x_{peak}$ investigated and the resolution required, the number of measurements N, starting voltage u_{start} and incremental voltage u_{step} is defined. The first working point i = 1 is selected.

Proceed as follows.

a) The transducer is excited by a stimulus $u_i + u_{ac} = u_{start} + i \times u_{step} + u_{ac}$.

b) At working point, i, the d.c. displacement, x_i, and a.c. state variables (such as a.c force F_{ac} and a.c. displacement x_{ac}) are measured after the transducer has reached steady state or a defined settling time T has passed.

c) The small signal parameters (such as $K_{inc}(x_i) = F_{ac}/x_{ac}$) are calculated at the particular working point x_i by using a linear model which is optimally fitted to the measured signal.

d) The next working point $i = i + 1$ is selected and steps 1 to 5 are repeated until $i > N$.

e) The parameter values are interpolated between the working points x_i with $i = 1, \ldots, N$ or the coefficients of the power series expansion (such as Equation (3)) are calculated.

10.4 Full dynamic method

10.4.1 General

The full dynamic method uses an a.c. stimulus of sufficient amplitude and bandwidth such as music or an audio-like signal (noise). Usually, there is no d.c. component in the stimulus. Measured state variables (voltage, current, displacement) are the basis for the identification of free parameters of the non-linear model (such as the lumped model in Figure 1). Based on identified state variables (such as voice coil temperature) and transducer nonlinearities (stiffness K_{ms}) the amplitude of the stimulus is adjusted automatically to operate the transducer at maximal amplitudes $-x_{peak} < x_i < x_{peak}$ safely and to avoid any damage of the transducer. Figure 4 shows the setup for dynamic measurement of large signal parameters.

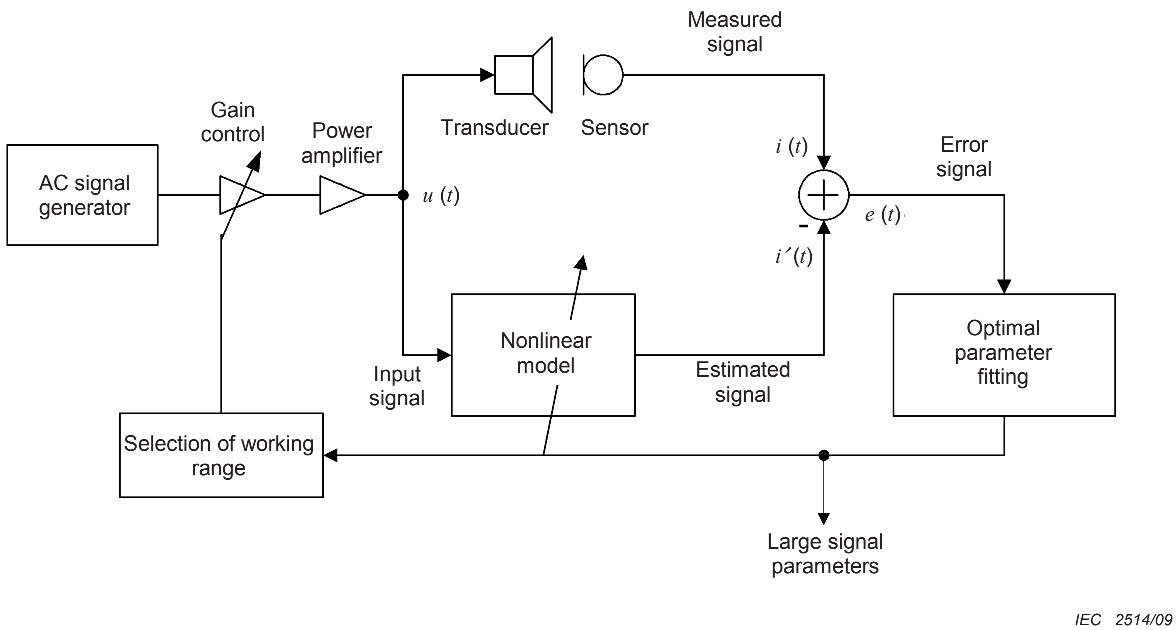


Figure 4 – Setup for dynamic measurement of large signal parameters

10.4.2 Requirements

A signal source is required providing an audio-like signal which is provided via a power amplifier to the loudspeaker terminals. A sensor is required to monitor at least one state variable (such as current) of the loudspeaker. A signal processing system is required to model the relationship between input signal (such as voltage) and monitored state variable (such as current) and to calculate the optimal parameters by using a fitting technique.

10.4.3 Procedure

Proceed as follows.

a) A broadband noise signal of small amplitude is supplied via a power amplifier to the terminals of the speaker (voltage supply).
b) The electrical input current i at the terminals or other state signals (displacement or sound pressure) is measured using a mechanical or acoustical sensor.
c) The input current $i'(t)$ is predicted using the nonlinear transducer model (such as lumped model in Figure 1). The error signal $e(t) = i(t) - i'(t)$ is calculated and the free parameters are estimated by minimizing the error signal $e(t)$.
d) The displacement limits x_{Bl} and x_C are derived from Equations (4) and (7). The increase of the voice coil temperature ΔT_V is estimated by monitoring the d.c. resistance R_e of the coil.
e) The amplitude of the stimulus is increased until the peak displacement x_peak exceeds either the force factor limited displacement, x_{Bl}, or the compliance limited displacement, x_C or the increase of the voice coil temperature ΔT_V exceeds the permissible limits.
f) Adequacy of the modeling and optimal parameter fitting shall be checked by calculating the mean squared error between measured and modeled response (such as current, velocity, displacement).

11 Nonlinear force factor

11.1 Force factor curve *Bl*(*x*)

11.1.1 Characteristic to be specified

The non-linear force factor, $Bl(x)$, is preferably reported as a graphical representation showing the parameter as a function of displacement, x, within the measured range $-x_\mathrm{peak} < x < x_\mathrm{peak}$ Positive displacement, x, corresponds to a deflection of the coil away from the back-plate. It is recommended that the displacement axis is labelled with verbal comments to support the orientation of the coil-in and coil-out position.

11.1.2 Method of measurement

11.1.2.1 General

The force factor characteristic may be measured by the static, point-by-point dynamic or the full dynamic method as defined in Clause 10. The method used shall be reported.

11.1.2.2 Coefficients of force factor expansion

The coefficients b_j with j = 0, 1, …, N in the power series expansion of the force factor curve

$$Bl(x) = \sum_{j=0}^{N} b_j x^j \qquad (3)$$

shall be reported with peak displacement x_peak describing the limits of the fitting range $-x_\mathrm{peak} < x < x_\mathrm{peak}$.

11.2 Force-factor limited displacement, X_{Bl}

11.2.1 Characteristic to be specified

The decrease of the Bl-value caused by a movement of the coil away from the rest position $x = 0$ limits the maximal peak displacement. The force-factor limited peak displacement x_{Bl} is implicitly defined by the condition that the minimal force factor ratio

$$\min_{-x_{Bl} < x < x_{Bl}} \left(\frac{Bl(x)}{Bl(0)} \right) 100\ \% = Bl_{\min} \qquad (4)$$

equals a defined threshold $Bl_{\min}$.

It is recommended to use a threshold of $Bl_{\min} = 82\ \%$ which corresponds with 10 % modulation distortion according to Clause 24 of IEC 60268-5 for a two-tone signal comprising a tone at resonance frequency $f_1 = f_s$ and a second tone at $f_2 = 8{,}5\ f_s$.

The peak value x_B shall be reported with the minimal force factor ratio, $Bl_{\min}$ used, for example:

$$x_{Bl} = 3\ \text{mm with } Bl_{\min} = 82\ \%$$

11.2.2 Method of measurement

The nonlinear force factor curve shall be measured according to 11.1.2.

The value $Bl(x = 0)$ at the rest position is determined and this value is multiplied by the threshold of the minimal force factor ratio (such as $Bl_{\min} = 82\ \%$).

The smallest displacement x for which $Bl(x_{Bl}) = Bl(x = 0)*Bl_{\min}$ gives x_{Bl}. See Figure 5.

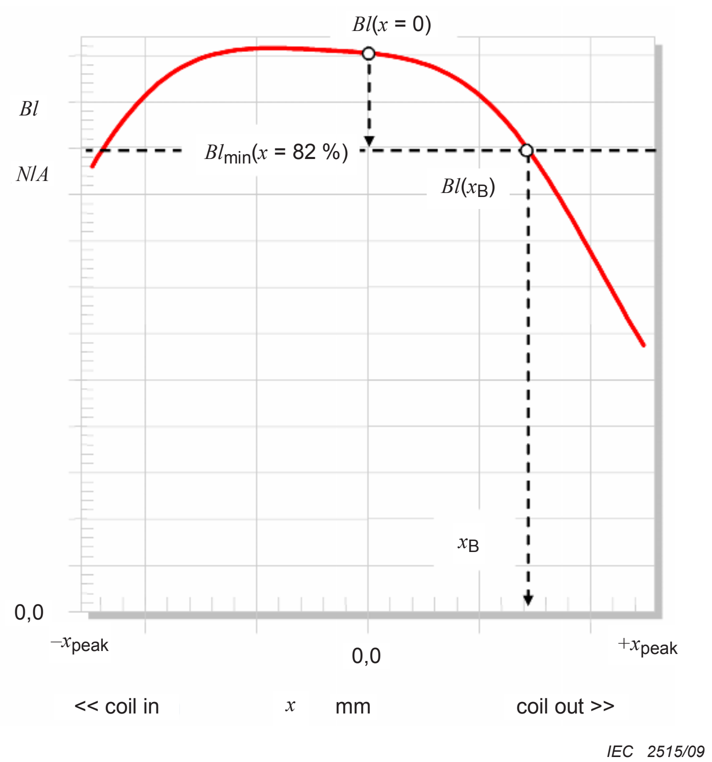


Figure 5 – Reading the maximal peak displacement x_B limited by force factor only

11.3 Symmetry point, $x_{sym}(x_{ac})$

11.3.1 Characteristic to be specified

The symmetry point in the Bl-curve describes the centre point between two points on the Bl-curve producing the same Bl-value

$$Bl(x_{sym}(x_{ac}) - x_{ac}) = Bl(x_{sym}(x_{ac}) + x_{ac}) \tag{5}$$

which are separated by 2 x_{ac}. The dependency of the symmetry point $x_{sym}(x_{ac})$ versus displacement x_{ac} shall be reported as a curve as shown in Figure 6.

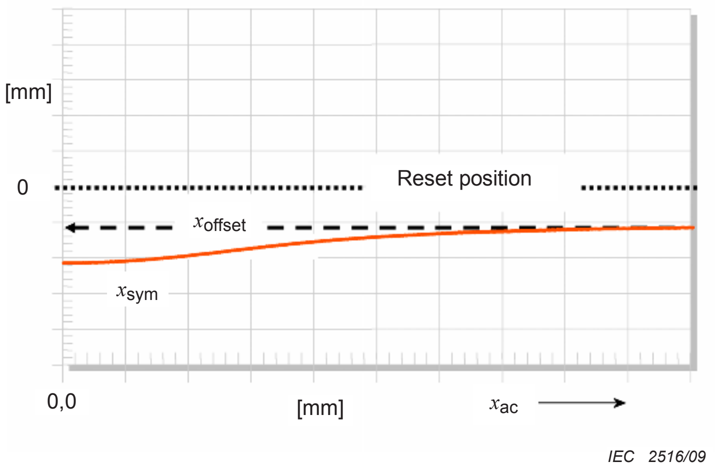


Figure 6 – Reading the voice coil offset from the symmetry point $x_{sym}(x_{ac})$ curve

11.3.2 Method of measurement

As illustrated in Figure 7, a Bl-value is selected which is smaller than Bl_{max} and the corresponding displacement values x_1 and x_2 are read on both sides of the Bl maximum giving $Bl(x_1) = Bl(x_2)$. The symmetry point $x_{sym} = (x_1 + x_2)/2$ and the displacement $x_{ac} = |x_2 - x_1|/2$ are calculated. The procedure is repeated for smaller Bl-values.

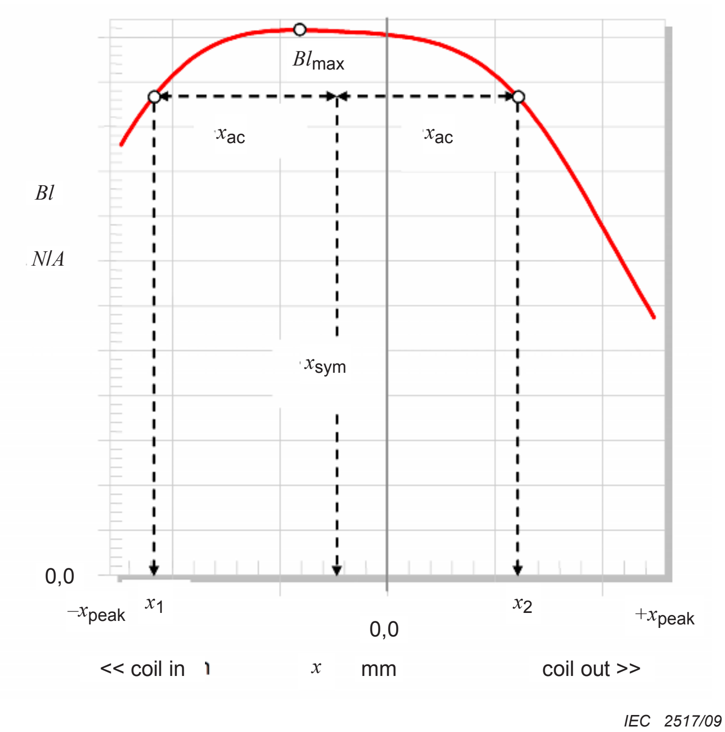


Figure 7 – Definition of the symmetry point x_{sym} in the nonlinear force factor characteristic $Bl(x)$

11.4 Voice coil offset, x_{offset}

The voice coil offset x_{offset} is the symmetry point $x_{sym}(x_{ac})$ for a high value of $x_{ac}(x_{ac} > x_{Bl})$ to assess the symmetry at the steep slopes of the Bl-curve. The voice coil offset x_{offset} is reported together with the amplitude x_{ac}, for example:

x_{offset} = 0,4 mm at x_{ac} = 5,2 mm

NOTE If the symmetry point varies significantly with the displacement ($x_{sym}(x_{ac}) \neq$ constant), the asymmetry of the Bl-curve is caused by the magnetic field geometry and cannot be compensated by a coil shift.

12 Nonlinear stiffness

12.1 Nonlinear stiffness curve $K_{ms}(x)$

12.1.1 Characteristic to be specified

The non-linearity of the suspension is preferably reported as a graphical representation of the stiffness showing the parameter $K_{ms}(x)$ as a function of displacement, x, within the measured range $-x_{peak} < x < x_{peak}$ as shown in Figure 8. Positive displacement, x, corresponds to a deflection of the coil away from the back-plate. It is recommended that the displacement axis be labeled with verbal comments to support the orientation of the coil-in and coil-out position.

NOTE The graphical representation of the nonlinear compliance $C_{ms}(x)$ which is the reciprocal of the nonlinear stiffness $K_{ms}(x)$ makes the interpretation of nonlinearity more difficult at higher displacements, where the impact of the nonlinearity on the restoring force is dominant.

12.1.2 Method of measurement

12.1.2.1 General

The stiffness characteristic shall preferably be measured by using the full dynamic method as defined in Clause 10, because it describes the behavior of the suspension for an audio-like stimulus best. The d.c. component in the stimulus used in static, quasi-static and point-by-point dynamic techniques causes significant differences in the measured stiffness due to visco-elastic behavior.

12.1.2.2 Coefficients of stiffness expansion

The coefficients k_i with j = 0, 1, ..., N in the power series expansion of the stiffness curve defined by

$$K_{ms}(x) = \sum_{j=0}^{N} k_j x^j \quad (6)$$

shall be reported together with peak displacement x_{peak} describing the limits of the fitting range $-x_{peak} < x < x_{peak}$.

12.2 Compliance-limited displacement x_C

12.2.1 Characteristic to be specified

The decrease of the compliance C_{MS}-value of the suspension caused by a movement of the coil away from the rest position x = 0 limits the maximal peak displacement. The compliance limited displacement x_C is implicitly defined by the condition that the minimal compliance ratio

$$\min_{-x_C < x < x_C} \left(\frac{C_{MS}(x)}{C_{MS}(0)} \right) 100\ \% = C_{min} \quad (7)$$

equals a defined threshold C_{min}.

It is recommended to use a threshold of C_{min} = 75 % which corresponds with 10 % harmonic distortion for a sinusoidal excitation tone at resonance frequency f_s. The limit used shall be reported with the displacement x_C, for example:

x_C = 2 mm at C_{min} = 75 %

12.2.2 Method of measurement

The nonlinear stiffness curve is measured according to 12.1. The compliance curve $C_{ms} = 1/K_{ms}(x)$ is then calculated. The value $C_{ms}(x = 0)$ is read at the rest position and this value is multiplied by the threshold of the minimal compliance ratio (such as C_{min} = 75 %). The smallest x for which the $C_{ms}(x)$ equals $C_{ms}(x = 0) \times C_{min}$ gives x_C.

12.3 Stiffness asymmetry $A_K(x_{peak})$

12.3.1 Characteristic to be specified

The asymmetry of the $K_{ms}(x)$ curve is assessed by a single value

$$A_K(x_{\text{peak}}) = \frac{2(K_{\text{MS}}(-x_{\text{peak}}) - K_{\text{MS}}(x_{\text{peak}}))}{K_{\text{MS}}(-x_{\text{peak}}) + K_{\text{MS}}(x_{\text{peak}})} 100\ \% \tag{8}$$

using the stiffness at the negative and positive limits $\pm x_{\text{peak}}$ of the measured K_{ms}-curve. It is recommended to measure the K_{ms} at high amplitude, so as to have $x_{\text{peak}} > x_{\text{C}}$. The peak displacement x_{peak} used for reading the stiffness asymmetry shall also be reported

$$A_K = 90\ \%\ (x_{\text{peak}} = 5{,}5\ \text{mm}).$$

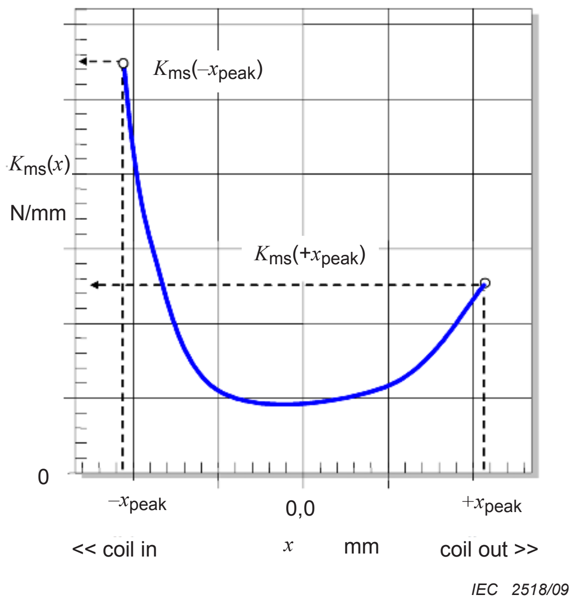


Figure 8 – Reading the stiffness asymmetry from the $K_{\text{ms}}(x)$ curve

12.3.2 Method of measurement

As illustrated in Figure 8, read the stiffness values at positive and negative peak displacement x_{peak} in the measured $K_{\text{ms}}(x)$ curve. Calculate the stiffness asymmetry A_K using Equation (8).

13 Displacement-dependent inductance, $L_e(x)$

13.1 Inductance curve $L_e(x)$

13.1.1 Characteristic to be specified

The non-linearity of the inductance is preferably reported as a graphical representation of the inductance parameter $L_e(x)$ as a function of displacement, x, within the measured range $-x_{\text{peak}} < x < x_{\text{peak}}$ without input current (i = 0). Positive displacement, x, corresponds to a deflection of the coil away from the back-plate. It is recommended that the displacement axis is labeled with verbal comments to support the orientation of the coil-in and coil-out position.

13.1.2 Method of measurement

13.1.2.1 General

The inductance curve characteristic may be measured by the point-by-point dynamic or the full dynamic method, as defined in Clause 10.

13.1.2.2 Coefficients of $L_e(x)$ expansion

The coefficients l_i with j = 0, 1, ..., N in the power series expansion of the inductance $L_e(x)$ defined by

$$L_e(x) = \sum_{j=0}^{N} l_j x^j \;\Big|\; i = 0 \tag{9}$$

shall be reported, together with peak displacement x_{peak} describing the limits of the fitting range $-x_{peak} < x < x_{peak}$.

13.2 Inductance-limited displacement, x_L

13.2.1 Characteristic to be specified

The variation of the electrical input impedance at higher frequencies caused by the nonlinear elements $L_e(x)$, $L_2(x)$ and $R_2(x)$ in the LR2-model, as shown in Figure 1, limits the maximal peak displacement. The inductance-limited displacement x_L is implicitly defined by the condition that the maximal impedance variation

$$\max_{-x_L < x < x_L} \left(\frac{|Z_e(x, f_2) - Z_e(0, f_2)|}{|Z_e(0, f_2)|} \right) 100\ \% = Z_{max} \tag{10}$$

equals a defined threshold Z_{max} using the frequency f_2 = 8,5 f_s where f_s is the resonance frequency.

It is recommended to use a threshold of Z_{max} = 10 % which corresponds with 10 % modulation distortion according to Clause 24 of IEC 60268-5 for a two-tone signal comprising a tone at resonance frequency $f_1 = f_s$ and a second tone at f_2 = 8,5 f_s.

The peak value x_L shall be reported with the threshold of the maximal impedance variation Z_{max} used, for example:

x_L = 3 mm at Z_{max} = 10 %

13.2.2 Method of measurement

The electrical input impedance $Z_e(x, f_2)$ is measured at frequency f_2 = 8,5 f_s (using the resonance frequency, f_s) by using the point-by-point dynamic or the full dynamic method according to Clause 10. The threshold for maximal impedance variation is defined (such as Z_{max} = 10 %). The smallest x where the $Z_e(x) - Z_e(x = 0)$ equals Z_{max} * $Z_e(x = 0)$ gives x_L.

14 Current -dependent inductance, $L_e(i)$

14.1 Characteristic to be specified

The non-linearity of the inductance is preferably reported as a graphical representation of the inductance parameter $L_e(i)$ as a function of displacement, i within the measured range $-i_{peak} < i < i_{peak}$ without coil displacement (x = 0).

14.2 Method of measurement

14.2.1 General

The inductance nonlinearity $L_e(i)$ shall be measured by the full dynamic method as defined in Clause 10.

14.2.1.1 Coefficients of $L_e(i)$ expansion

The coefficients f_i with j = 0, 1, ..., N in the power series expansion of the Inductance $L_e(i)$ defined by

$$L_e(i) = \sum_{j=0}^{N} f_j i^j \quad \Big| x = 0 \tag{11}$$

shall be reported together with peak current i_{peak} describing the limits of the fitting range $-i_{peak} < i < i_{peak}$.

15 Parameters derived from geometry and performance

15.1 Maximal peak displacement, x_{MAXd}

The maximal peak displacement, x_{MAXd} is, derived from the nonlinear distortion measured in the sound pressure output. x_{MAXd} is defined as the peak displacement of the voice-coil, at which the maximum value of either the total harmonic distortion, d_t, or the second-order modulation distortion, d_2, or the third-order modulation distortion, d_3, in the radiated sound pressure is equal to a defined threshold, d (used as subscript in x_{MAXd}), for example x_{MAX10} = 3 mm at d = 10 %.

15.2 Method of measurement

15.2.1 General

The driver is excited by the linear superposition of a first tone at the resonance frequency, $f_1 = f_s$, and a second tone, $f_2 = 8{,}5\, f_s$, with an amplitude ratio of 4:1. The total harmonic distortion, d_t, assesses the harmonics of f_1 and the modulation distortions, d_2 and d_3, are measured according to Clause 24 of IEC 60268-5. It is recommended to measure the sound pressure in the near field of the driver and to use a threshold d = 10 %.

15.2.2 Peak displacement, x_{lin} limited by motor geometry

The peak displacement x_{lin} describes the ideal linearity of an overhang or underhang configuration and is defined by

$$x_{lin} \frac{\left| h_{coil} - h_{gap} \right|}{2} \tag{12}$$

using the coil height h_{coil} and gap depth h_{gap} specified by the manufacturer. The actual distribution of the magnetic field within the gap and outside (fringe field) is neglected.

15.2.3 Excursion limit, x_{mech}

The excursion limit x_{mech} describes the maximal travel of the coil without considering distortion of the output signal. This value may be derived from the geometry of the moving coil assembly and the suspension but should be verified by practical testing to ensure that the loudspeaker can be operated up to x_{mech} without being damaged.

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