
**Non-destructive testing — Methods for
absolute calibration of acoustic emission
transducers by the reciprocity technique**

*Essais non destructifs — Méthodes d'étalonnage absolu des capteurs
d'émission acoustique par la technique de réciprocité*

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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 organizations, 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.

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In exceptional circumstances, 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), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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Introduction

A standard method for primary calibration of acoustic emission transducers, ISO 12713:1998^[1], introduced the seismic surface pulse method for Rayleigh surface wave calibration, wherein the breaking of a glass capillary is employed for the sound source and a standard capacitive transducer is used for the measurement of dynamic displacements of the surface. In ISO 12714:1999^[2], on secondary calibration of acoustic emission sensors, a transducer which has been calibrated by the seismic surface pulse method is employed for comparison of reception sensitivity.

This Technical Report describes the methods for calibrating absolute sensitivity of acoustic emission transducers, both to Rayleigh surface waves and longitudinal waves, by means of a reciprocity technique. Since reciprocity parameters have been derived, absolute sensitivity can be determined by purely electrical measurements without the use of mechanical sound sources or reference transducers.

Procedures of the seismic surface pulse method and reciprocity technique differ from each other; however, there is a common theoretical basis in the two calibration methods. For the seismic surface pulse method, theoretical surface displacements were calculated on the basis of Lamb's theory (Reference [7]). For the reciprocity calibration, reciprocity parameters for the Rayleigh wave calibration were also derived from Lamb's theory. As for the Rayleigh surface wave calibration, a round robin experiment was carried out in a collaborative effort between the USA and Japan, and it was ascertained that absolute sensitivities as obtained by either method agreed well.

The aim of both methods is the same, namely, to establish uniformity of acoustic emission testing, to form a basis for data correlation, and to provide for the interpretation of results obtained by different laboratories at different times.

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This Technical Report describes methods for three-transducer calibration, two-transducer calibration, and impulse response calibration, respectively. In three-transducer calibration, three acoustic emission transducers of the same kind, which are reversible transducers, are prepared to configure three independent pairs of transmitting and receiving transducers on a solid transfer medium. Transmission signal current and reception signal voltage are measured on each pair as a function of frequency, and frequency responses of amplitude of absolute sensitivity both to the Rayleigh surface waves and longitudinal waves are determined on each transducer. Once three-transducer calibration has been carried out, an optional transducer, which is not necessarily a reversible transducer, can be calibrated by a relatively simple procedure by using the calibrated transducer as a reference of transmission or reception. In two-transducer calibration, frequency responses of amplitude of absolute reception sensitivity are determined on an optional transducer by using one acoustic emission transducer, the transmission responses of which have been calibrated by the three-transducer calibration. In addition, by means of three-transducer calibration, impulse responses of each acoustic emission transducer can also be determined. In the impulse response calibration, frequency responses of phase angle, in addition to amplitude, of absolute sensitivity are measured by three-transducer calibration on the basis of complex reciprocity parameters, and impulse responses are determined through inverse Fourier transform of the frequency responses of amplitude and phase.

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Non-destructive testing — Methods for absolute calibration of acoustic emission transducers by the reciprocity technique

1 Scope

This Technical Report describes the method of three-transducer calibration for calibrating frequency responses of absolute sensitivity by means of a reciprocity technique using three reversible acoustic emission transducers of the same kind, the method of two-transducer calibration for calibrating frequency responses of reception sensitivity of an optional acoustic emission transducer by using one acoustic emission transducer, the transmission responses of which have been calibrated by three-transducer calibration, the method for impulse response calibration for calibrating impulse responses of absolute sensitivity through inverse Fourier transform of the frequency responses measured by the three-transducer calibration, and the method for representing the calibration results.

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.

ISO 12716:2001, *Non-destructive testing — Acoustic emission inspection — Vocabulary*
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3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12716 and the following apply.

3.1

reciprocity technique

calibration method on three reversible acoustic emission transducers of the same kind, wherein transducers are arranged on a solid transfer medium so that they configure three independent pairs of transmitting and receiving transducers, and absolute sensitivity is determined only by electrical measurements of transmission current and reception voltage on each pair

3.2

reversible transducer

transducer which can be used both for transmission and reception

3.3

absolute sensitivity

quantity of reception voltage sensitivity or transmission current response of an acoustic emission transducer

3.4

reception voltage sensitivity

ratio of the open-circuit output voltage of an acoustic emission transducer used for reception to the vertical component of displacement velocity at the position where the transducer is to be placed

- 3.5**
transmission current response
ratio of the vertical component of displacement velocity at the index point to the input current of an acoustic emission transducer used for transmission
- 3.6**
index point
position on the surface of the transfer medium, which is located at the specified distance in the specified direction from the acoustic emission transducer used for transmission, and used as the reference of transmission response
- 3.7**
reciprocity parameter
ratio of reception sensitivity to transmission response of an acoustic emission transducer which is a reversible transducer
- 3.8**
transfer medium
solid block on the surfaces of which transducers are placed in the calibration so that they configure a pair of transmitting and receiving transducers of the Rayleigh surface waves or longitudinal waves
- 3.9**
calibration signal
electrical voltage signal which is applied to the transmitting transducer in the calibration
- 3.10**
tone burst signal
calibration signal consisting of sinusoidal waves with a specified frequency and a specified period modulated so that the envelope forms one squared cosine
- 3.11**
calibration frequency
frequency of sinusoidal waves of which a tone burst signal consists
- 3.12**
squared-cosine signal
calibration signal which trigonometrically increases from zero to a maximum and decreases to zero during a specified period
- 3.13**
Hanning window
cosine-type time window with a specified period, which is used for Fourier transform of transmission and reception signals measured in the impulse response calibration
- 3.14**
Rayleigh wave calibration
calibration by which sensitivity to Rayleigh surface waves is determined by using Rayleigh waves for transmission and reception
- 3.15**
longitudinal wave calibration
calibration by which axial sensitivity to longitudinal waves is determined by using longitudinal waves for transmission and reception
- 3.16**
three-transducer calibration
calibration by a reciprocity technique, wherein frequency responses of amplitude of reception voltage sensitivity and/or transmission current response are determined on each of the three acoustic emission transducers

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3.17**two-transducer calibration**

calibration on an optional acoustic emission transducer which is not necessarily a reversible transducer, wherein frequency responses of amplitude of reception voltage sensitivity are determined by using one acoustic emission transducer for transmission, the transmission current response of which has been determined by three-transducer calibration

3.18**impulse response calibration**

calibration on three reversible acoustic emission transducers of the same kind, wherein impulse responses of reception voltage sensitivity are determined through inverse Fourier transform of the frequency responses of amplitude and phase of absolute sensitivity measured by three-transducer calibration

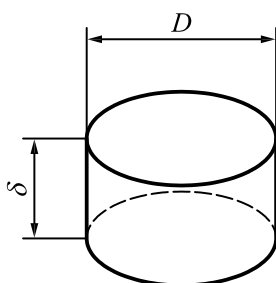
4 Preparation for calibration**4.1 Transfer medium and calibration signal**

The transfer medium should be made of a material whose density and elastic moduli are as close as possible to those of the actual object on which acoustic emission transducers are intended for use. In this Technical Report, carbon steel is principally assumed to be the material of possible objects. While any solid can be used for the transfer medium, forged steel is most recommended. The transfer medium should undergo ultrasonic testing in order to assure that detectable flaws or inclusions, which may affect the Rayleigh wave or longitudinal wave calibration, are not included. Namely, in longitudinal ultrasonic testing at a frequency between 2 MHz and 5 MHz, the medium should contain no flaws which give a reflection greater than 10 % of the first back-wall reflection. The planes of the transfer medium, used for the longitudinal wave calibration, should be parallel within $0,2^\circ$.

At the measurement of reception signals in the calibration, discrimination between the direct wave of the Rayleigh waves or longitudinal waves, which is the object of measurement, and other spurious waves is made on the basis of the propagation time of each wave. A larger dimension of the medium causes longer differences in the propagation time between waves, and consequently, the period T of a tone burst signal used in three-transducer or two-transducer calibration, or the period T_w of a Hanning window used in impulse response calibration, can be set longer.

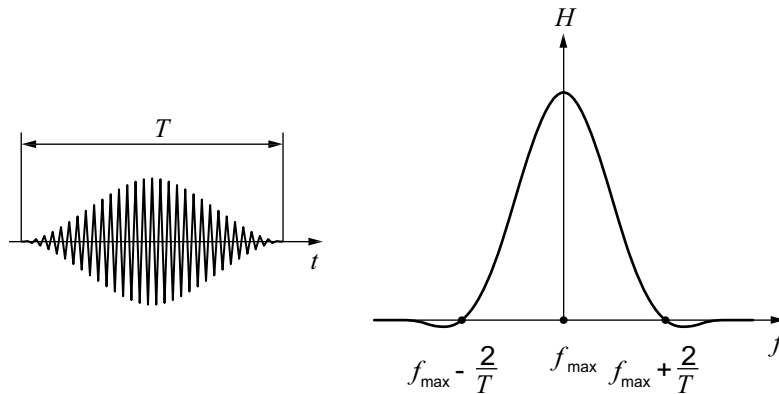
Figure 1 shows examples of setting on the period, T , in seconds, of a tone burst signal or the period, T_w , in seconds, of a Hanning window in relation to the dimension of a cylindrical transfer medium made of forged steel. In general, the shape of the medium is not limited to a cylinder. A rectangular medium, for instance, may be used as long as its volume contains the cylinder.

Figure 2 shows an example of the waveform and frequency spectrum of a tone burst signal with a period, T , in seconds, and a calibration frequency, f_{\max} , in hertz.



Diameter	Thickness	Tone burst signal period or Hanning window period
D m	δ m	T or T_w s
0,4	0,19	0,000 05
0,6	0,38	0,000 1
1,2	0,76	0,000 2

Figure 1 — Dimension of transfer medium and setting of period T or T_w



Key
H amplitude
f frequency
f_{max} maximum calibration frequency
T period
t time

Figure 2 — Waveform and frequency spectrum of a tone burst signal

4.2 Mounting of acoustic emission transducer

Sensitivity of acoustic emission transducers depends on the mounting method, namely, the contact pressure, couplant, and surface roughness of the object. The contact surface pressure of the transducers under calibration should be not less than 0,1 MPa, and machine oil is recommended as the couplant for use on steel. The surfaces of the transfer medium, on which acoustic emission transducers are mounted in calibration, should have a root mean square surface roughness value *R*, in metres, so that Condition (1) is satisfied:

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$$R \leq \frac{20}{f_{\max}} \tag{1}$$

where *f_{max}* is the maximum frequency, in hertz, of calibration.

The distance between the transmitting and receiving transducers on the transfer medium should be so set that each transducer is located in a far field of the mating transducer. In Rayleigh wave calibration, the distance, *r_R*, in metres, should be set so that Condition (2) is satisfied:

$$r_R \geq \frac{f_{\max}}{c_R} d^2 \tag{2}$$

In longitudinal wave calibration, the distance, *r_L*, in metres, should be set so that Condition (3) is satisfied:

$$r_L \geq \frac{f_{\max}}{c_L} d^2 \tag{3}$$

where

d is the diameter, in metres, of the transducer element,

c_R, *c_L* are propagation velocities, in metres per second, of Rayleigh and longitudinal waves in the transfer medium, respectively.

The propagation velocities are given by Equations (4) and (5):

$$c_R = \frac{1}{Y} \left[\frac{E}{2(1+\mu)\rho} \right]^{1/2} \quad (4)$$

$$c_L = \left[\frac{(1-\mu)E}{(1+\mu)(1-2\mu)\rho} \right]^{1/2} \quad (5)$$

where

E is the Young modulus, in newtons per square metre, of the transfer medium;

μ is the Poisson ratio of the transfer medium;

ρ is the density, in kilograms per cubic metre, of the transfer medium;

Y is a constant which depends on the Poisson ratio.

Table 1 shows the numerical values of Y .

4.3 Calculation of reciprocity parameters

Reciprocity parameters, essential both for three-transducer calibration and the impulse-response calibration, are dependent not on the transducer design but on the mode of waves, constants of the medium, and definition of sensitivity. Amplitude $|H_R(f)|$ and phase angle $\angle H_R(f)$ of the reciprocity parameter for Rayleigh wave calibration are given at a frequency, f , in hertz, by Equations (6) and (7), respectively:

$$|H_R(f)| = 2\pi f \frac{1+\mu}{E} k_R X \left(\frac{2}{\pi k_R r_R} \right)^{1/2} \quad (6)$$

$$\angle H_R(f) = \frac{\pi}{4} - k_R r_R \quad (7)$$

where

$$k_R = \frac{2\pi f}{c_R}$$

X is a constant which depends on the Poisson ratio. Table 1 also shows the numerical values of X .

Amplitude $|H_L(f)|$ and phase angle $\angle H_L(f)$ of the reciprocity parameter for longitudinal wave calibration are given at a frequency, f , in hertz, by Equations (8) and (9), respectively:

$$|H_L(f)| = 2f \frac{(1+\mu)(1-2\mu)}{E(1-\mu)r_L} \quad (8)$$

$$\angle H_L(f) = \frac{\pi}{2} - k_L r_L \quad (9)$$

where

$$k_L = \frac{2\pi f}{c_L}$$