Absolute Calibration of Acoustic Emission Transducers 
as per CEN ISO/TR 13115 in Disuse of Mechanical Sound Sources or 
Reference Transducers 

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Abstract 
While CEN ISO/TR 13115 ‘Methods for absolute calibration of acoustic emission transducers by the 
reciprocity technique’ was published in December 2011 as a common technical document of CEN and 
ISO, the author would like to emphasize the indispensable nature of transducer calibration for further 
development in research and practical applications of acoustic emission. 
This paper outlines the contents of TR 13115, and refers to a technical question on the reciprocity 
theorem in the calibration, which was raised and resolved during the standard development process in 
ISO. Furthermore, it was made clear by experimentation that the calibration of acoustic emission 
transducers is necessary, not only for quantitative evaluation, but also for mutual comparison of data 
obtained by different laboratories. Unless transducer calibration is carried out, physical quantities of 
acoustic emission cannot be measured on the basis of electrical signals from the transducers. 

Keywords: CEN, ISO, Technical Report, acoustic emission transducer, absolute calibration, 
reciprocity technique, sensitivity, Rayleigh wave, longitudinal wave 

1. Introduction 

For absolute calibration of acoustic emission transducers, a reciprocity method was 
implemented by the author approximately forty years ago, and has since been utilized by a 
number of transducer manufacturers and laboratories in the world [1]-[6]. As a consequence, 
CEN ISO/TR 13115 ‘Methods for absolute calibration of acoustic emission transducers by the 
reciprocity technique’ was published in December 2011 as a common technical document 
(Technical Report) of CEN (European Committee for Standardization) and ISO (International 
Organization for Standardization) [7]. 

An outstanding advantage of the reciprocity method is that absolute sensitivity, including 
frequency characteristics and impulse responses, to both modes of Rayleigh waves and 
longitudinal waves, can be determined at any place by means of purely electrical 
measurements without the use of mechanical sound sources or reference transducers. 

The author would like to emphasize the indispensability of the calibration of acoustic 
emission transducers, not only for quantitative evaluation, but also for mutual comparison of 
data obtained by different laboratories [8]-[16]. 

This paper outlines the contents of TR 13115, and refers to a technical question on the 
reciprocity theorem in the calibration, which was raised and resolved during the standard 
development process in ISO. Furthermore, it was clear through experimentation that the 
sensitivities and frequency characteristics of commercial transducers possibly diverge from 
product to product, even within the same lot of the same model. Significant differences are of 
course, also observed between different models. In addition, even for a single transducer, its 
characteristics generally vary with the modes of incident waves.
Table 1. Results of final vote on CEN ISO/TR 13115.

<table>
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It should be recognized that the transducer calibration is a starting point for further development in research and applications of acoustic emission. However to our regret, most people seem to have overlooked the important role of the transducer calibration. Without absolute calibration, any physical parameters of acoustic emission cannot be measured on the basis of electrical signals from the transducers.

2. CEN ISO/TR 13115

The new work item proposal for the Technical Report was approved in May 2009 in both CEN/TC 138 Non-destructive testing and ISO/TC 135/SC 9 Acoustic emission testing. The draft was reviewed and edited under the ISO-lead mode of collaboration between CEN and ISO as defined in the Vienna Agreement. After completion of the due process, the final draft was submitted for a parallel approval vote in ISO and a formal vote in CEN, and was approved for publication in August 2011. Table 1 shows the voting results in CEN and ISO.

Table 2 summarizes the contents of CEN ISO/TR 13115 [7]. It is written in Introduction as follows: 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 (for information), 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.

3. Reciprocity in Calibration

With regard to the reciprocity theorem, which provides a theoretical basis for reciprocity calibration of acoustic emission transducers designated in CEN ISO/TR 13115, a technical question was raised during the discussions for the standard development process in ISO. In response to this, the author reported on the results of an experiment to corroborate reciprocity in reciprocity calibration. Experts on the project team approved and accepted his explanation as follows:

3. 1. Reciprocity Theorem [17], [18]

For reciprocity calibration, three independent pairs of transmitting and receiving transducers are configured by means of three acoustic emission transducers under calibration. Each pair can be regarded to form a two-port electrical network (a kind of four-terminal network or quadrupole).

Figure 1 shows the correspondence of the transducer pair, composed of two transducers T₁ and T₂, to a two-port network.

According to reciprocity theorem for a two-port network, the following equation is derived:
Figure 1. A pair of transmitting and receiving transducers, and a corresponding two-port electrical network.

\[
\frac{E_{12}}{I_{12}} = \frac{E_{21}}{I_{21}},
\]

where \( I_{12} \) is transmission current and \( E_{12} \) is reception voltage in Case 1, and \( I_{21} \) is transmission current and \( E_{21} \) is reception voltage in Case 2.

It should be notified that \( E_{12} \) does not consistently equal \( E_{21} \) unless characteristics of both the transducers, \( T_1 \) and \( T_2 \), are completely identical to each other. Consequently in general,

\[
E_{12} \neq E_{21}.
\]

3.2 Experimental Results

Table 3 shows a list of acoustic emission transducers used for the present experiment. For Experiment 1, transducers of the same model were used to configure a pair of transmitting

Table 3. Pairs of transducers used for experiment.

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<th>Experiment</th>
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<th>( T_2 )</th>
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<td>Experiment 1</td>
<td>Model: AE 3-1.5 (Φ3×1.5)</td>
<td>Model: AE 3-1.5 (Φ3×1.5)</td>
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<td>Experiment 2</td>
<td>Model: AE 3-1.5 (Φ3×1.5)</td>
<td>Model: FC 1045S (Φ10×2)</td>
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Figure 2. Two models of transducers. (Left: FC 1045S, Right: AE 3-1.5)
and receiving transducers. For Experiment 2, transducers of different models were used.

Model AE 3-1.5 employs a disk-type piezoelectric element with a 3-mm diameter and 1.5-mm thickness, while Model FC 1045S employs an element with a 10-mm diameter and 2-mm thickness. Figure 2 shows a photo of the two transducer models.

For the experiment, transducers were arranged similarly to the measurement of Rayleigh wave calibration. Both the transmitting and receiving transducers were mounted at a distance $D_R$ apart from each other on the same plane of a transfer medium. A rectangular block of forged steel was employed as the transfer medium. Both the height and width of the block were 0.82 m, thickness was 0.38 m, and the distance $D_R$ was set to 0.2 m.

Figure 3 summarizes the experimental results. The ratios of the reception voltage $E$ to the transmission current $I$ were determined as a function of frequency. In both Experiment 1 and Experiment 2, the ratios in Case 1 and Case 2 are consistent with each other.

3. 3 Conclusion

As a consequence of the experiment, it has been corroborated that the reciprocity holds for the transducer pair of different models, as well as for the pair of the same model of transducers.

4. Calibration Results

Figure 4 summarizes the calibration results from four different models of commercial transducers. For each model, three transducers in the same lot were calibrated by ‘three-transducer calibration’, as is designated in CEN ISO/TR 13115. Frequency responses of amplitude of absolute sensitivity both to the Rayleigh surface waves and longitudinal waves were determined on each transducer in the range from 100 kHz to 1 MHz.
Longitudinal wave calibration              Rayleigh wave calibration

(a) Model ‘A’

(b) Model ‘B’

(c) Model ‘C’

(d) Model ‘D’

Figure 4. Calibration results from commercial transducers.
Significant differences are of course observed from model to model. Sensitivities can diverge significantly from product to product, even within the same lot of the same model. Transducers generally assume different sensitivities with different modes of incident waves.

In the case of Rayleigh waves [19], the diameter of the transducer element affects the frequency characteristics of sensitivity due to aperture effect. Crests and troughs of incident Rayleigh waves cancel each other within the aperture of the element. It is well known that longitudinal waves are primarily detected in bulky objects, such as concrete structures, while Rayleigh waves are dominant in thick plate objects, such as pressure vessel walls. Consequently, transducer calibration is generally required at least for both longitudinal waves and Rayleigh waves.

5. Conclusions

Unless absolute calibration of the employed transducers has been carried out, it is not possible to study the physical quantities of the observed acoustic emission on the basis of electrical signals from the transducers. It should be recognized that those who have overlooked the transducer calibration, are discussing only the characteristics of electrical signals, in place of physical properties of acoustic emission itself. The author would very much appreciate it if the important role of the transducer calibration, for instance, as it is designated in CEN ISO/TR 13115, be recognized by more people involved in acoustic emission research and applications.

Acknowledgements

The author would express his deepest gratitude to Mr. Peter Tscheliesnig, Chairman of CEN/TC 138/WG 7, Mr. Pedro Feres, Chairman of ISO/TC 135/SC 9, and all of the CEN and ISO people, who endeavored for the publication of CEN ISO/TR 13115. His gratitude is extended to Mr. Makoto Koshimura, Mr. Toshiaki Tanaka and Mr. Keisuke Shibata for their experiment.

References