METHOD OF ACOUSTIC EMISSION SENSOR CALIBRATION

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ABSTRACT

The paper reviews the background, methodology and standardization of calibration of acoustic emission sensors. The reciprocity methods of absolute calibration are closely described. This method was practically realized with vector signal analyser HP 89410A. As a transfer medium for wave propagation, a large steel block was used.

1 INTRODUCTION

Acoustic Emission (AE) is a passive non-destructive testing technique that has been used widely since 1970s. AE has been defined as the spontaneous release of elastic energy by material when it undergoes deformation.

Good metrology of AE calibration method is necessary to compare results of calibration made by other departments or to compare effect of ageing, thermal cycling and so on. ASTM E1106 outlines a method for primary calibration of AE sensors and ASTM E976 and E1781 for secondary calibration.

Basic problems of calibration are:

- The instantaneous displacement of a point at the surface is a three-dimensional vector but the output of the transducer is a scalar quantity.
- Loading effect due to the mechanical impedance of the transducer on the surface of the block affects measurement
- Output signal is a function of displacement of measured surface contacted by surface of sensor. The function is not only a function of time but also a function of position within the measurement area of the transducer.

From previous follows some assumptions, which are supposed to be accomplished. First condition is that transducers used for acoustic emission measurement are in general sensitive only to surface motion normal to the surface they are attached. Secondly, it is assumed that the loading effect due to the mechanical impedance of the transducer on the block surface has no effect on the displacement under the transducer. Finite size of sensors surface is often missed out. We can ignore the effect if the radius of active element is negligible compared with length of the wave. Active element surface should be as small as possible. For example, a sensor with diameter 3 mm can be used up to frequency 500 kHz on steel block with acceptable measurement error. The coupling of the sensor to the structure can be a major source of the poor repeatability. The temperature can affect the parameters of a couplant and piezoelectric constant too.

2 ACOUSTIC EMISSION SENSORS

Transducers used for acoustic emission measurement are in general sensitive to surface motion normal to the surface to which they are attached. Typically, AE transducers are sensitive to frequencies above 100 kHz. Resonant transducers are highly sensitive to a very narrow frequency range, which must be carefully selected depending on the application. Resonant transducers in the region 150 kHz to 300 kHz are probably the most widely used in AE applications. The highest frequencies likely to be of interest to users of AE transducers are in the range from 800 kHz to 1 MHz.

There are several ways how this transduction can be achieved. The piezoelectric effect, capacitance methods and optical interferometry are common techniques used for detection of AE in industry and research.

TYPE OF TRANSDUCER	SENSITIVITY [m]	WIDTH OF THE BAND [MHz]
Piezoelectric resonant	10^{-13}	0,1 to 0,3
Piezoelectric wideband	10^{-12}	0,1 to 2
Capacitance	10^{-11}	DC to 50
Laser interferometer	10^{-10}	0,05 to 100

Tab. 1: *Typical sensitivities of AE sensors*

3 ACOUSTIC EMISSION SENSORS CALIBRATION

Lead problem of sensors calibration is to find a characteristic of the transducer. A frequency response of specific sensor on the mechanical input quantity (velocity, displacement) is the most common result of calibration.

Environment for waves propagation is called testing block. It is usually a high homogeneity steel block with block or cylinder shape. Size of block has to be sufficient to get response of direct wave, not reflected wave. That limits a length of time window, low threshold frequency and resolution of calibration. A defined source (simulated source of AE) affects surface of test block. Waves spread in block and are detected by transducer binded on the surface. Simulated source can be fall of steel ball, helium jet, spark discharge, pencil lead break, capillary break, generation by piezoelectric sensor, laser etc.

There are two types of AE sensors calibration:

Primary calibration has to know absolute value of input signal and his shape. A mechanical source of input signal with defined parameters (shape of waveform – step or impulse, duration) is important aspect. In case of calibration with step or impulse input signal, the transfer function is defined by comparison of known spectrum of input signal with spectrum of transducer. The method of calibration with step function is described in ASTM E 1106 [2] and reciprocity calibration in NDIS 2109 [3].

Secondary calibration requires reference sensor with known characteristics. Calibration is done by comparison of results of reference and tested transducer. Data from secondary calibration are the same type as from primary, but are more limited (in frequency, absence of shift characteristics, and greater error of calibration). The method of secondary calibration is standardised by ASTM E 1781 [4] and ASTM E 976 [5]. Recommended configuration includes tested sensor, reproducible reference source, medium for wave propagation – steel cone with cut off top in an oblique surface and a measuring device.

4 COMPARISON OF METHOD OF RECIPROCITY CALIBRATION

- *Hatano at al [6]:* Forms basic of Japan standard NDIS 2109 [6]. It needs three reversible transducers. Amplitude and phase of frequency transmission are result of calibration. Three currents and voltages are measured. Transducers are drived by harmonic pulse with frequency in desired range. There is a need of large testing block and less common equipment (for example current probe).
- *Ohtsu – Ono [7]:* It needs three transducers (only two reversible). Amplitude of frequency transmission is a result of calibration. Three input and output voltages are measured and impedance of sensor two. Transducers are drived by jump in voltage. Impedance of one sensor is measured on desired range of frequency. A spectrum is counted by FFT. A test block is quite small and equipment is common. But there is need of special SW to compute transmission of test block.
- *Hill – Adams[8]:* Only theoretical analysis. It uses three no calibrated sensors, one of them must be reversible (a transmitter). Amplitude of frequency transmission is result of calibration. Sensors are drived by current. Three currents and voltages are measured.
- *Leschek (US Pat 4039767)[9]:* Analogous requirements as Hill – Adams. It has very simplified calculation of reciprocity parameter.

5 ESTABLISHING ACOUSTIC EMISSION RECIPROCITY CALIBRATION AT FEKT

Selection of instruments was limited by the capability of our laboratory and by instruments used by Hatano at al. Here is the list of used components:

- Vector signal analyzer HP 89410A, two channels DC up to 10 MHz, GPIB interface, sampling rate up to 25,6 MHz
- Arbitrary waveform generator HP 33120A. A waveform can have up to 16000 points, resolution 12 bits, 40 MSa/s, GPIB interface
- Current probe Tektronix P6022 with impedance matching. Sensitivity 1 mA/mV or 10 mA/mV. Bandwidth on range 1 mA/mV is 8,5 kHz up to 100 MHz.
- Personal Computer Pentium 4 3,2 MHz, 512 MB RAM, GPIB-USB, OS WinXP
- AE amplifier with gain 30 dB in range from 35 kHz to 4 MHz, for drop 3 dB.

- Steel cylinder with diameter 94,0 cm, height 43,8 cm. Used material is signed 34 MnV (0,34 C). To interference suppression was the block grounded with HP 89410A.
- Binding paste Krautkramer TGT, number 50472.
- GPIB and sensor cables

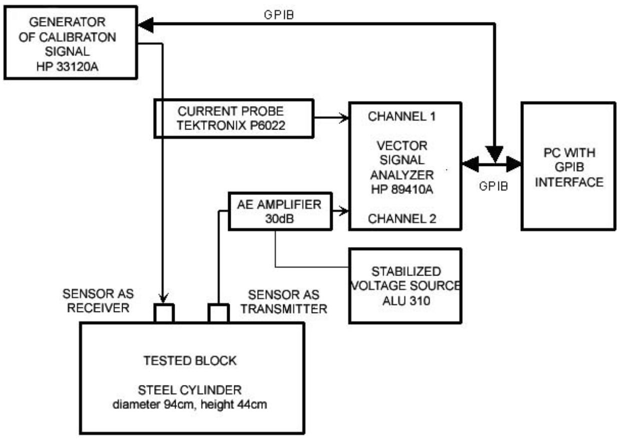

Fig. 1: *Configuration of test stand*

The length of driving signal was 100 μs according to size of testing block. First reflected wave from the bottom side came after 150 μs. Sampling rate was 25,6 MHz. Source signal was generated from 4000 points. Length of time window was 200 μs. Experiment was managed by SW made in LabVIEW. Frequency transmission was probe from 60 kHz to 1 MHz point to point with step 5 kHz. Result characteristic have only 189 frequency points and the experiment took 1,5 hour, it means 10 s per a point. Setting of sensitivity of input channels and loading dates to generator is the most time-consuming. Low frequency is limited by length of input signal; high frequency is limited by sensitivity of transducer.

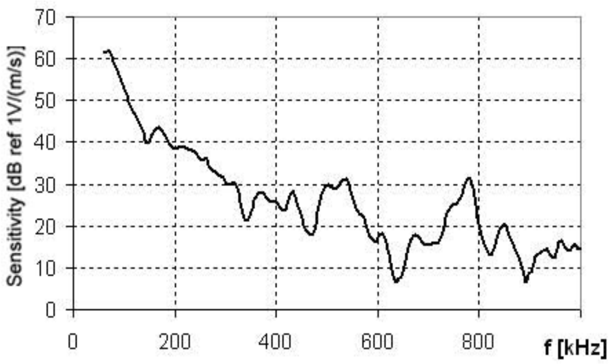

Fig. 2: *Characteristic of transducer UT1000 measured by reciprocity calibration*

On the figure 2 there is an example of measured frequency characteristic of transducer UT 1000. The characteristics correspond up to 0,5 MHz with characteristic gets from manufacturer Physical Acoustic Corporation.

6 CONCLUSIONS

The paper reviews the standardization of primary and secondary calibration of acoustic emission sensors. The reciprocity method of absolute calibration was practically realized with vector signal analyser HP 89410A, generator HP33120A, a large steel block and current probe Tektronix P6022. The whole experiment was managed by PC with LabVIEW. Interface GPIB was used. The program and measuring apparatus enable primary reciprocity calibration of AE sensors based on NDIS 2109-91. Advantages of this method are: finding of absolute frequency characteristic, method doesn't need special sources of input signal and there are no problems with calculation of spectrum. Disadvantages are small frequency resolution and long duration of calibration. The duration is partially compensated by computing frequency response of three transducers.

Plans for the future are following. To improve apparatus by automatic switching of inputs and outputs so the whole process will be automatic. Next point is to use power amplifier to increase amplitude of input signals and to decrease noise for frequency where the transducers have small transmission.

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