An Ultrasound Technique for the Characterization of the Acoustic Emission of Reinforced Concrete Beam

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Abstract. Among the various non-destructive techniques for health monitoring in structures, the Acoustic Emission (AE) is well known in scientific literature. Ultrasonic waves emitted by the creation and propagation of cracks in concrete or Reinforced Concrete specimens are usually collected by means of ultrasonic sensors. The signals must be treated in front-end readout process with preamplifiers and filters, to be able to set a proper trigger level and to cut the background noise (belonging to different frequency ranges). In addition, the post processing of the data is important to "clean up" the dataset, removing fake events, and to extract the proper information, useful for structure damage assessment. In this paper, the authors present the experimental set up and the transducers used to acquire the AE signals recorded during a four-point bending test on a RC beam. The ad hoc realized amplifier and filtering circuit used in the test are also described. Then, an example of an AE signal is also reported, in terms of frequency spectrum analysis and noise filtering.

Keywords: Acoustic Emission · Piezoelectric Sensor · Filters
Amplifiers

1 Introduction

The Acoustic Emission analysis is a well-known non-destructive test for structures (see for example [1, 2]). The study of ultrasonic waves produced by Reinforced Concrete (RC) specimen under load, is extremely interesting to understand damaging and breaking behaviour [3, 4]. For this purpose, the need for an efficient read out electronics

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and off line data processing is evident. AE signals, in fact, are usually of a small amplitude. For this reason, it is extremely important to properly match the frequency range of the events with the bandwidth of the sensors. In addition, a preamplifier and filtering circuit is needed, both to improve the signal/noise ratio and to remove background noise from low frequency signals (both mechanical and electrical).

In this paper, the authors present the sensors used in a four-point bending test performed at the University of Salerno. In [5], the authors presented the results of the test under the civil engineering point of view, underlining several parameters that allow to evaluate the damage in the specimen. The aim of this paper, is to present the electronic approach, in terms of readout electronics, pre-amplification filtering circuits and post processing procedures, that led to the data collection and analysis.

2 Four Points Bending Test

A four-point bending test on a reinforced concrete beam was performed at the Laboratory of Materials and Structures of the Department of Civil Engineering of the University of Salerno (Fig. 1).

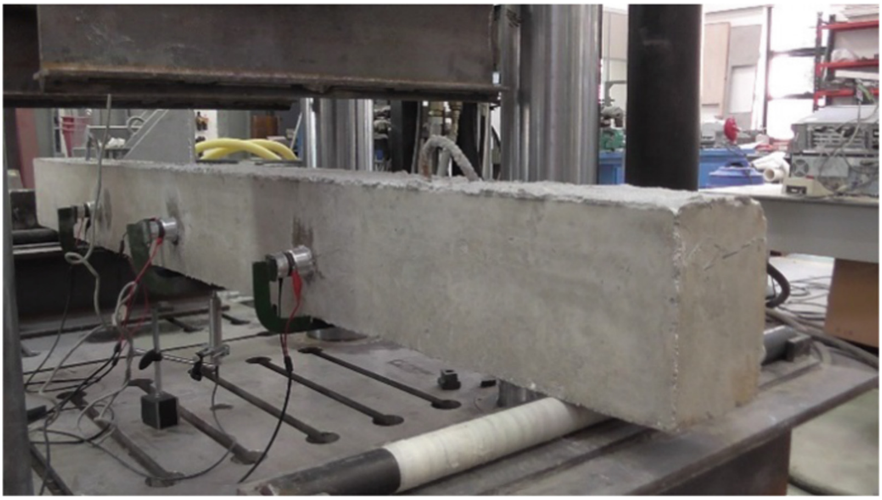

Fig. 1. Picture of the experimental set up.

In order to measure the Acoustic Emission (AE) and to match the AE frequency, two kinds of Ultrasonic Transducers were used: the lower frequency transducer is a classical Langevin transducer (LT) (see Fig. 2(a)) with a resonance frequency of about 40 kHz; in order to measure the higher AE frequency, the ultrasonic transducer (HFT) shown in Fig. 2(b) was used. To characterize both transducers we measured their electrical input impedance Z_i; in Fig. 3, the amplitude of the LT Z_I is shown evidencing its resonance frequency at 43.4 kHz.

Fig. 2. (a) Picture of the classical Langevin transducer (LT) and (b) of the high frequency ultrasonic transducer (HFT) used.

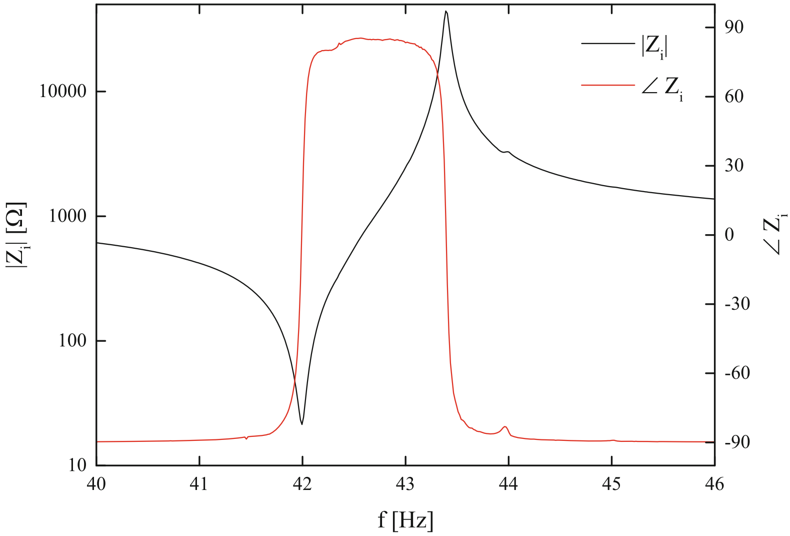

Fig. 3. Amplitude ($|Z_i|$) and phase ($<Z_i$) of the electrical input impedance of the Langevin transducer.

The HFT is composed by a thick piezoelectric disk (t_D = 10 mm) with a diameter d_D = 25 mm glued to a aluminum disk with the same diameter and a thickness t_s = 12 mm. In Fig. 4 the electrical input impedance of the HFT is reported; as it can be seen, there are many resonance frequencies around 200 kHz, a frequency of interest for the application. The purpose of the aluminum disk in front of the PZT emitting surface is to acoustically match the piezoceramic disk to concrete [6].

In Fig. 5 the four-point bending test on a reinforced concrete beam, performed at the Laboratory of Materials and Structures of the Department of Civil Engineering of the University of Salerno is shown. The simply supported, 150 $\times$ 200 mm^2 cross-section beam with length equal to 2000 mm, was loaded in two points 625 mm far

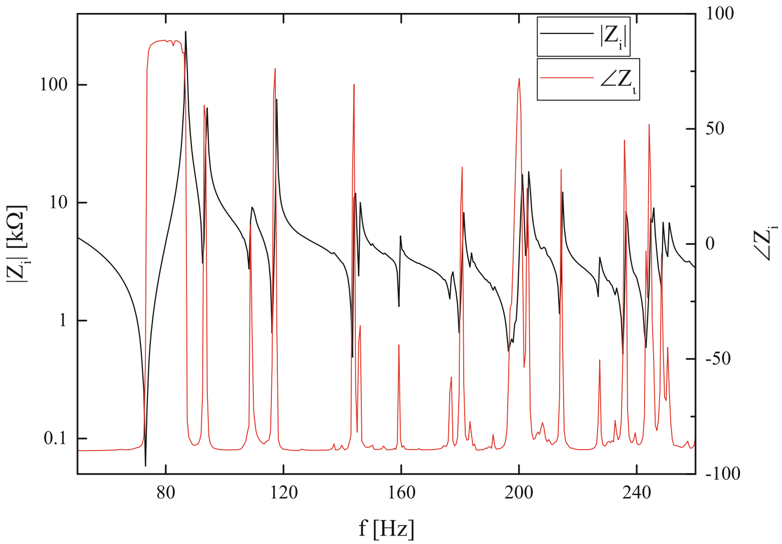

Fig. 4. Amplitude ($|Z_i|$) and phase ($<Z_i$) of the electrical input impedance of the high frequency ultrasonic transducer (HFT) in Fig. 2(b).

from the supports by means of a stiff steel beam transferring the load from a hydraulic jack. The load was applied in displacement control, according to a protocol involving preliminary increasing cycles and then a ramp until failure. The total force F transferred by the hydraulic jack and the displacement at mid-span were recorded by the central unit; the analytical values of first-cracking and ultimate loads are F_{cr} = 10.05 kN and F_u = 91.97 kN respectively. To measure the beam acoustic emission, we used three Langevin transducers (LT) and one high frequency transducer (HFT). In Fig. 5 the positions of the Langevin transducers on the beam are evidenced by circles named 1, 2 and 3 while the HF transducer position is reported with the circle named 4. A picture of the experimental set up is shown in Fig. 1.

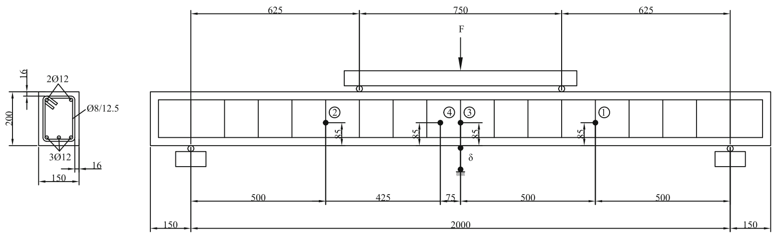

Fig. 5. Sketch of the RC beam under test with sensors positions (circles).

In order to amplify the signal received by all transducers we designed and realized an amplifier whose circuit is shown in Fig. 6(a). The circuit is a voltage amplifier and it was repeated four times in order to amplify all the transducer signals and to enhance the signal to noise ratio (SNR). The amplifier gain can be adjusted from 10 to 100, but we used the 10 gain in order to avoid saturation at high AE. The voltage amplifier in Fig. 6 (a) is followed by the high pass filter (HPF) in Fig. 6(b), needed to avoid both electric and mechanical low frequency noise. The cascade of the amplifier and the HPF shows a −3 dB bandwidth between 2.5 kHz and 140 kHz with a gain of 38.

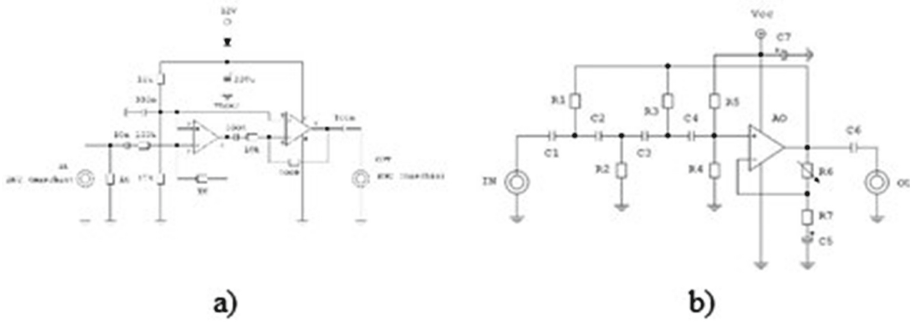

Fig. 6. Schematic of the (a) voltage amplifier, (b) High Pass Filter HPF.

The circuit amplifying the HF transducer output is not provided with the HPF because the high frequency limit is less than the transducer resonance. In order to measure the AE we connected the transducers amplifiers' output to the four channels of a Lecroy "Waverunner 104 MXI" digital oscilloscope; we recorded, for each transducer 1213 AE events, each composed by 5002 points. In order to process the measurements, we developed a "Matlab" script that, first of all, filters the signals according to their amplitude. The filtering amplitude can be selected according to acquired signals, in the

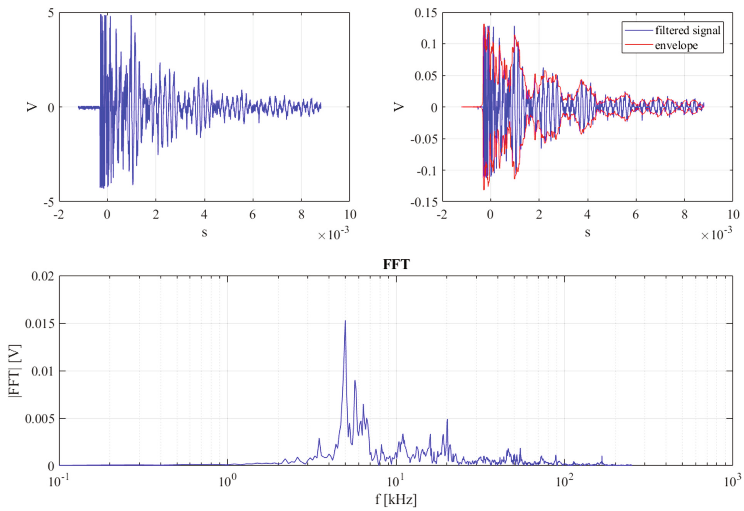

Fig. 7. The acquired AE signal.

present case we selected a filtering amplitude of 50 mV. In this way the 1213 events were reduced to 910. The next steps were the cancellation of the signal offset, about 48 mV in our case, and the cancellation of noise overlapping the signal in the amplifier band. This last step is performed by using an adjustable noise threshold; the threshold value was selected at 150 mV. Finally, the last step, before computing the AE quantities of interest was the elimination the elimination of the gain factor for the LT (38) and for the HFT (10). As an example of the AE first steps process, in the Fig. 7 is reported an AE signal (a) as acquired by the oscilloscope at the output of the Langevin transducer, (b) after the filtration and the envelope, in red, and (c) the FFT of the filtered signal.

3 Conclusions and Future Work

Two considerations can be done on the results shown: the first one is the analysis of the sensors sensitivity in order to select the transducer with highest performance. The other is that the analysis of the recorded AEs is crucial in order to study the RC specimen response under load and its durability and resistance. Future steps of this work will be the optimization of the data acquisition process and the physical analysis of the frequencies activated during the test.

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