 by M.-H. Yang and C.-P. Chou

A LAB-SCALE DIGITAL ACOUSTIC EMISSION SYSTEM FOR SOURCE LOCATION

Acoustic emission (AE) techniques have been used in the study of crack location, cracking mechanisms, deformation of metals and leak detection. In these techniques, AE sensors hit by transient stress waves generate AE signals, and then the AE signals are analyzed with various methods. Conventional AE systems only record some parameters of the AE signals, such as peak amplitude, ringdown counts, duration, risetime, and so on. On the other hand, a fully digital AE system can digitize the waveforms of AE signals and perform various analyses. Since many versatile and relatively cheap personal computers (PC), analog-to-digital (A/D) cards, and digital signal processing (DSP) software packages for PC are available, a fully digital and PC-based lab-scale AE system for 3-D source location can be set up. With the results of DSP for simulated and real AE signals, features of this AE system and critical factors involved are presented.

CONFIGURATION OF AE SYSTEM

The configuration of our AE system is shown in Fig. 1. Appropriate AE sensors and amplifiers can be employed, depending on the purpose of testing. Low-frequency (30 kHz) AE sensors were used in our leak testing. The A/D cards were two Nicolet BE493 A/D cards, working at a sampling rate of 200 kHz per channel for a total number of 8 channels. This means an approximate 7-times sampling of signals and a time resolution of 5 microseconds. Digitized AE signals were stored in an ordinary WINTEL PC, and MATLAB was used for data processing. Not only the AE sensors and amplifiers were exchangeable, but also the PC, A/D cards and the analysis software, so this system was highly flexible.

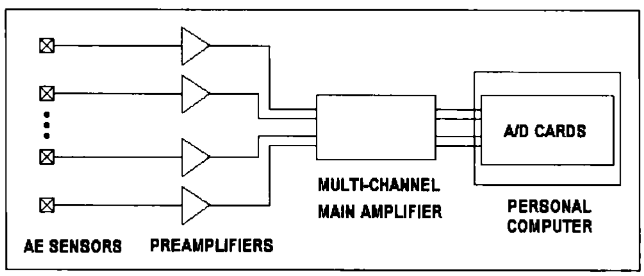

Fig. 1: The configuration of AE system

SAMPLING RATE

For a digital AE system to perform properly, sampling at a rate high enough is a prerequisite. Because of the nature of irreproducibility of AE phenomena, AE signals simulated by software were used to evaluate the influence of sampling rate. Assume a circle with a diameter of 12 meters is on the XY plane and centered at the origin. Six AE sensors were assumed to have been mounted, equally spaced along the circumference of this circle. Then, an imaginary square mesh with an edge of 12 meters, 0.5-meter interval, also centered at the origin, is placed on the XY plane. This results in 25 × 25 mesh points. Since the propagation speed of AE burst is known, the time needed for an AE burst from any mesh point to reach each sensor is known. That is, there is a set of arrival-time differences (delta-T's) for each mesh point. To calculate the source position for a set of burst-type AE signals, a straightforward "shift and add" method was used. First, assuming the AE source is at a mesh point inside the circle, the signal waveform of each channel was shifted forward in the time domain, with the corresponding delta-T value. Each time-shifted waveform was added to that of the first-hit channel, and then the resultant additive waveform was squared to give the signal power from that mesh point. When these operations have been performed for all mesh points, a power map can be created, and the peak of power map is considered the closest point to the AE source. Figures 2 shows a set of simulated signals, with the AE from (1, 2), propagating at 1480 m/s, of 10 kHz carrier frequency and sampled at 100 kHz. With this sampling rate, a series of location results for various carrier frequencies of signal (10, 20, and 50 kHz) are shown in Figure 3–5. It was found that when the sampling rate was 5 times the carrier frequency or higher, source location results were good no matter where the postulated source was. As the sampling rate lowered, other peaks began to emerge on the power map. When the sampling rate was 2 times the carrier frequency, marginally meeting the Nyquist criterion, the location result was incorrect. The same result was obtained when evaluating with cross-correlation method.

If a signal appears with infinite duration and excellent repetition, as those examples often shown in textbooks when the Nyquist criterion is stated, a sampling rate of two times the carrier frequency is sufficient. In AE testing or our sim-

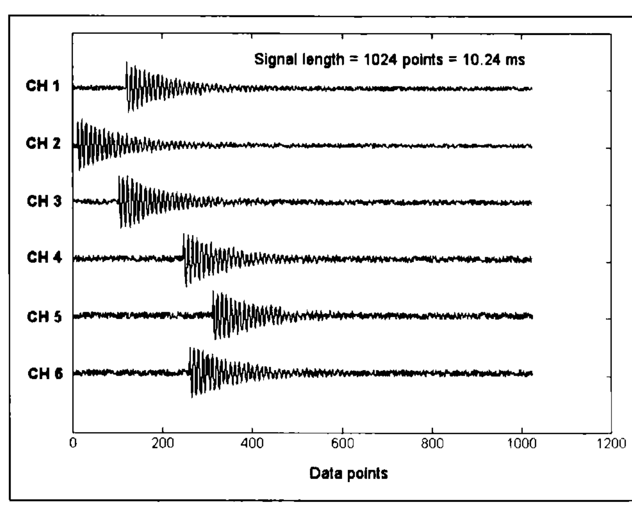

Fig. 2: A set of AE signals generated by simulation

M.-H. Yang is a Research Scientist at Materials Research Lab, Hsinchu, Taiwan. C.-P. Chou is a professor in the Department of Mechanical Engineering at National Chiao-Tung University.

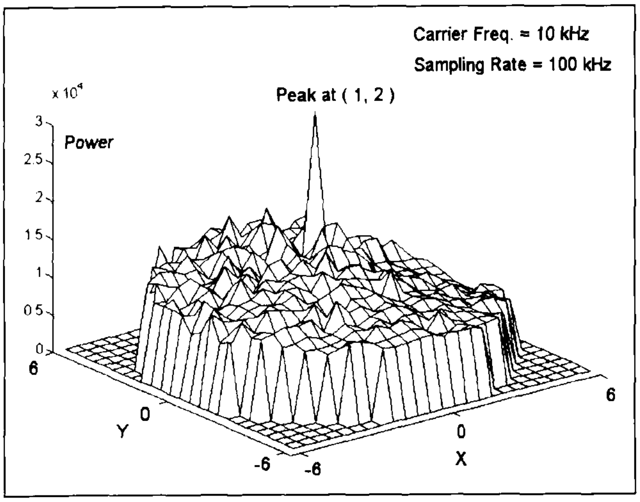

Fig. 3: Source location result when carrier frequency is 10 kHz

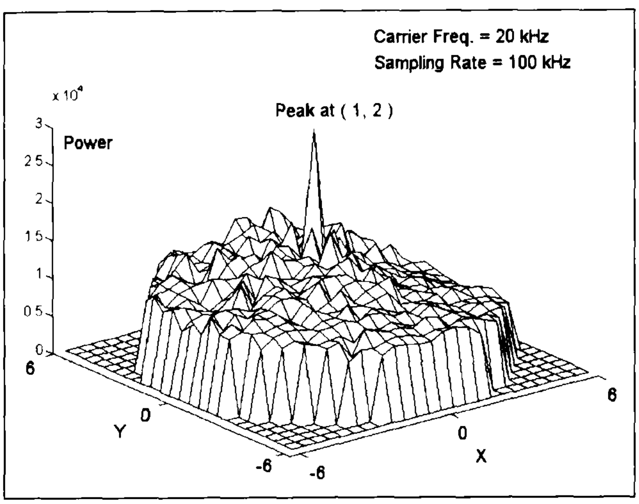

Fig. 4: Source location result when carrier frequency is 20 kHz

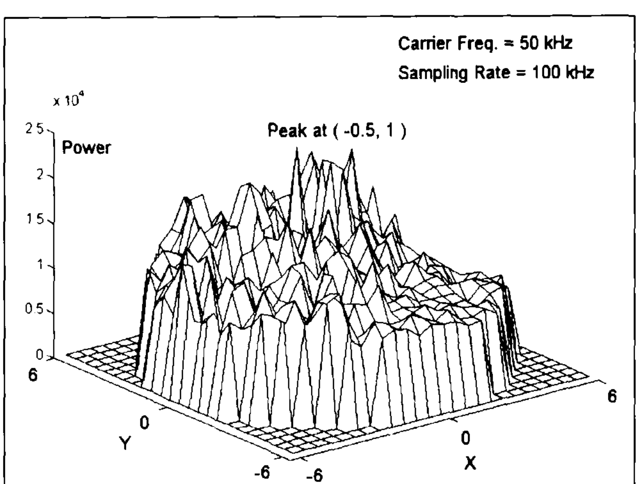

Fig. 5: Source location result when carrier frequency is 50 kHz

ulation where signals are of finite duration and consist of noise, a sampling rate of Nyquist frequency seems insufficient. As a rough approximation, an AE signal $h(t)$ can be simulated by a sinusoidal function with an exponential decay envelope along with noise, that is, $h(t) = Ae^{-\alpha t}\cos(2\pi ft) + noise$, where A and α are constants, t is time, and f is the carrier frequency. The frequency spectrum of this signal exhibits a bell-shape (due to the exponential decay), and is shifted and centered at f (due to modulation). As the signal becomes shorter (greater α), plus the effect of noise, the bell-shaped curve spreads. This means more frequency (and time) information will be lost if the sampling rate is fixed at Nyquist frequency, then the result of data processing will tend to be incorrect.

DIGITAL SIGNAL PROCESSING

To pinpoint the position of an AE source, the propagation speed of AE burst, the hit-sequence, and the delta-T's must be known. Conventionally, the "threshold-crossing method" is used: when the AE signal crosses a preset threshold of a channel, this channel is considered "hit" by the AE burst, and the time of crossing is defined as the arrival time. Then the hit-sequence and delta-T's are deduced thereafter. Threshold setting is user-dependent and somewhat subjective, but usually it is set at 6 dB (two times) higher than background noise. Because of the random nature of noise, in practice the threshold-crossing method is susceptible to noise, therefore leading to erroneous location results.

To make our system more robust to noise, a series of digital signal processing techniques were used. First, a digital band-pass (BP) filtering was applied to each digitized waveform of AE signal, according to the nominal frequency of AE sensors used. For instance, a BP filter of 20–40 kHz is used for AE sensors of 30 kHz. Second, filtered AE signals were transformed to their corresponding analytic signals[1]. With an analytic signal, the information of amplitude vs. time is kept but the oscillation term is suppressed. Third, the threshold-crossing method was applied to determine arrivals. Finally, the cross-correlation between two analytic signals was performed to give the relative arrival-time between two channels, then the hit-sequence and delta-T's were determined. Since the maximal value of cross-correlation indicates the relative time-shift between two main energy packets, correct hit-sequence and delta-T's can be deduced even in the presence of noises. Figure 6 shows a set of AE signals due to the leakage through a drilled hole in a leak experiment. As shown in Figure 6, in source location calculation, it is a common practice to set a certain time window which at least is equal to the maximal possible arrival-time difference between AE sensors, and then analyze the signals within the time window only. This also reduces calculation time significantly. The corresponding normalized analytic signals within the time window are shown in Figure 7. The noise was rather low, so the main energy packets (designated by "P") can be easily identified. Figure 8 shows another set of AE signals that are weaker and severely "contaminated" by noise. Since there are many "noise packets" (designated by "n" in Figure 9), conventional threshold-crossing method will lead to incorrect result. However, by using cross-correlation the correct result still can be obtained.

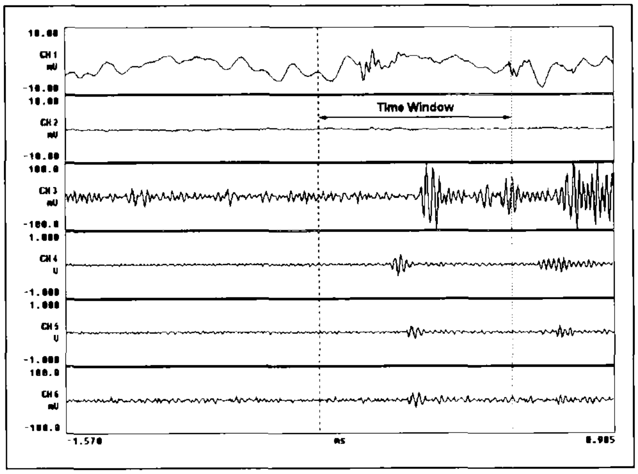

Fig. 6: A set of AE signals obtained in a leak experiment. The partial loss of couplant resulted in the lower signal amplitude of channel 6.

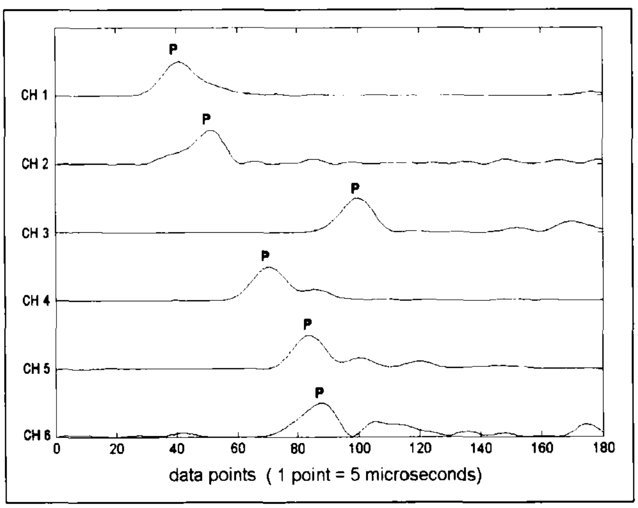

Fig. 7: The normalized analytic signals of AE signals within the time window in Figure 6. The main energy packets ("P") can be easily identified.

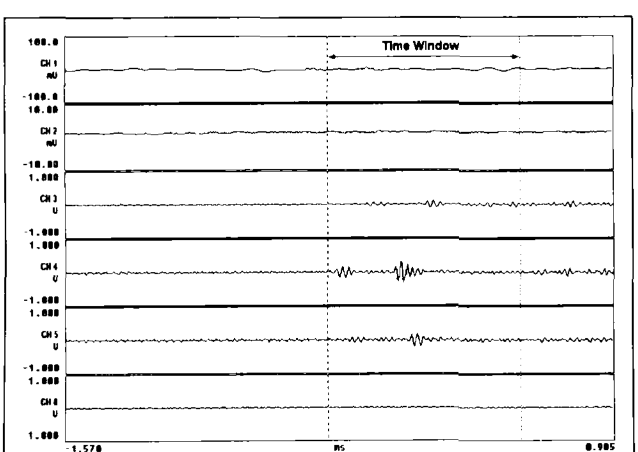

Fig. 8: Another set of AE signals obtained in a leak experiment

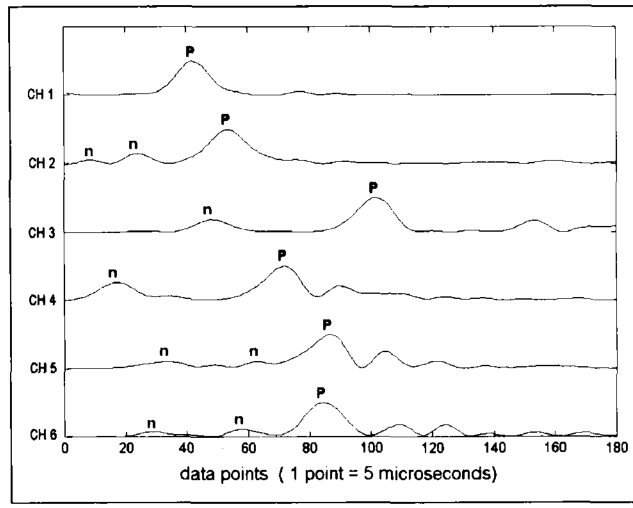

Fig. 9: The normalized analytic signals of AE signals within the time window in *Figure 8*. *Many noises ("n") are present.*

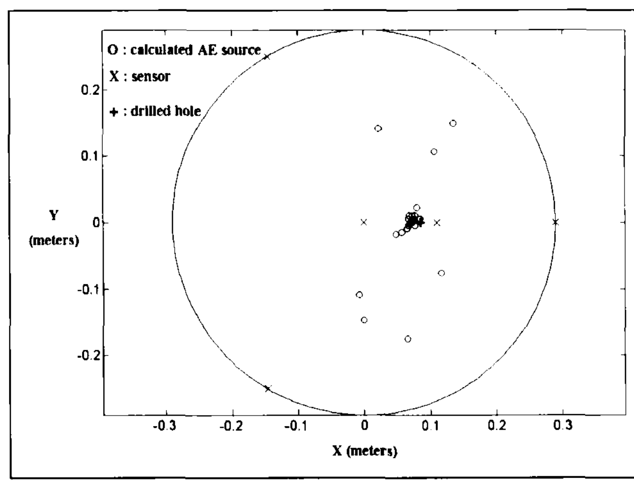

Fig. 10: Some location results of the AE signals in the leak experiment

3-D SOURCE LOCATION

When hit-sequence and delta-T data are available, calculations can be conducted to determine the location of an AE source. Various algorithms of AE source calculation have being developed, but the Spherical Interpolation (SI) method for 3-D location by Smith and Abel[2] was adopted. The SI method consists of a series of matrix computations, and is implemented with MATLAB. Some location results of the AE signals from leakage are shown in Figure 10, which is the projection of 3-D locations on the XY-plane. The calculated positions show good consistency and are very close to the leak hole.

CONCLUSIONS

A PC-based, fully digital and lab-scale acoustic emission system for 3-D source location was set up. To get good results, a sampling rate higher than the Nyquist frequency is preferred, and is at least five times the carrier frequency of signal for our experiment. With digital filtering, analytical signals, and cross-correlation technique, the source location operation can be made more robust to noise. Versatile 3-D source location calculation can be implemented with numerical and DSP software packages.

ACKNOWLEDGMENT

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