ACOUSTIC EMISSION EXPERIMENTS FOR
SAFETY OF NUCLEAR REACTOR VESSELS*

S. P. Ying
(Southwest Res. Inst., San Antonio)

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mission.
1) Hydrostatic experiments on flawed pressure vessels

Two series of tests of 6-inch-thick flawed steel vessels during static loading were conducted. In the first series of experiments, one precracked notch was introduced on the outer surface of the vessel wall of each of two vessels without nozzles. Then the two vessels were tested, one at 32°F and one at 132°F, below and above the transition temperature of the nuclear reactor grade steel (A-533, Grade D). In the second series of experiments, a precracked notch was created at the inner surface of the nozzles in two pressure vessels.

The two vessels were also tested at temperatures below and above the transition temperatures: one at 75°F and one at 190°F. The vessel tested at 75°F had a nozzle of A508-2 forging steel and a cylinder of A533, Grade B, Class 1 plate. The cylinder as well as the nozzle of the vessel tested at 190°F was A508-2 forging steel.

Six acoustic emission monitoring channels with an on-line minicomputer were used for each of the hydrostatic tests of the flawed pressure vessels. Acoustic emission was monitored in the frequency range from 100 to 300 kHz. The total gain of each channel was set at an equal level for each test, but the gain was varied from 80 to 90 dB for individual tests. The computer cathode ray tube (CRT) screen graphically displayed the number of acoustic emission events at individual locations on the vessel in cylindrical coordinates. The details of the monitoring system can be found elsewhere.

Cumulative acoustic emission events from the crack of each vessel was plotted as a function of strain.

Below the yield points, each set of the acoustic emission data shows relatively large slopes. The peaks of these emission rates for the cracks in nozzles occur at vessel pressures of 8 ksi and 10 ksi for the tests of 75°F and 190°F, respectively. These values of vessel pressures are lower than the corresponding values for flaws in cylindrical vessel walls simply because the stress fields in flaw vicinities in nozzles are higher than those in cylindrical vessel walls for a given value of vessel pressure.

The slopes of acoustic emission events vs. strains in a log-log scale are larger for higher test temperatures. This systematically varies with the elastic limits at different test temperatures. However, when the acoustic emission data were plotted versus the peak nozzle corner strain—which is larger than the average strain at the tip of a crack in nozzle—the slopes, as expected, are smaller in comparison with data obtained from tensile tests. Prior to vessel failure, the acoustic emission behavior observed in these two series of tests was similar. There were no significant increases in both the number of events and the amplitude of emission prior
to a catastrophic failure from the crack below the transition temperature. But both the events and the amplitudes increased rapidly under ductile failure above the transition temperature.
2) Thermal shock experiments

Thermal shock is a potential problem of nuclear power reactors during an emergency shutdown. A series of thermal shock experiments was conducted with two 5.75-inch-thick flawed cylindrical specimens other than the four flawed vessels used in the pressure vessel tests. The first test was classified as a no-crack propagation experiment, and the second was a crack propagation and arrest experiment. Hydraulic flaw noise and cavitation noise were generated during thermal shock by cooling liquid. These acoustic background noises were analyzed before each thermal shock test for proper selections of monitoring frequency-range and the sensitivity of the monitoring system.

The 5.75-inch-thick flawed cylindrical specimens were 36 inches high with a 9.5-inch inner diameter. The flaw of the first thermal shock experiment was 36 inches long and approximately .4 inch deep. A semicircular flaw on the second specimen was 1-1/2 inches long and approximately 3/4 inch deep. The material of the specimens was A508 forging steel.

The test specimens were preheated to 550°F uniformly; then the specimens were quenched by a cooling liquid with an initial temperature of 40°F for the first test and -9.5°F for the second. The cooling liquid flowed through the specimens from the bottom to the top at a flow rate of 250 gal/min for the first experiment and 500 gal/min for the second.

Four acoustic emission monitoring channels were used in the thermal shock tests. A 1/8-inch-diameter and 15-inch-long carbon steel waveguide was installed for each channel on the test vessel with a 30 lb spring load and a high temperature grease coupling. The overall frequency response of the waveguide and the transducer was nearly equal (within ±5 dB) in a frequency range from 120 to 600 kHz. In order to overcome the acoustic background noise, a 120-kHz high-pass filter was used in each preamplifier of 40 dB, and a bandpass filter from 120 to 600 kHz was used in each signal conditioner. The total maximum gain of each channel was less than 80 dB.

The cumulative acoustic emission events $n_e(t)$ from the crack region is plotted as a function of time, $t$, during the first test in Fig. 1. From the curve $n_e(t)$, the time rate of change of events can be calculated, which gives an exponential decay curve as shown in Fig. 1.

Since high amplitude emission was detected without extremely high emission rate during the thermal shock test, the maximum thermal stress probably reached a level such that $K_I/K_{IC} = 0.8$, but did not reach the value of crack propagation in the base metal as predicted.

In the crack propagation and arrest experiment, three acoustic pulses were emitted from the crack in the inner surface of the cylindrical wall. Two of the events were generated at each of two tips of the crack, which
was consistent with the indication of crack propagations by the strain gages mounted at those locations.

The crack was examined after the thermal shock test. It was found that the crack was extended about 1.5 inches at one tip and about 2.5 inches at the other. Therefore, the 2 events, at least, were acoustic emission resulting from crack propagation. Since the acoustic emission was detected through a 40 dB preamplifier only, the emission must be relatively strong in comparison with the emission related to plastic deformation and approaching to crack initiation detected in the first thermal shock test.

Fig. 1. Acoustic Emission in the First Thermal Shock Test