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Experimental Investigations of Cavitation Using Acoustic Emission Transducers

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EXPERIMENTAL INVESTIGATIONS OF CAVITATION USING ACOUSTIC EMISSION TRANSDUCERS

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INTRODUCTION

Acoustic emission equipment is normally associated with the monitoring of solids under stress. A common example of acoustic emission is the microfracturing of a body under load. As materials are stressed microcracks occur when the localized stress exceeds the fracture strength of the material. The formation of microcracks is coupled with the release of energy in the form of transient elastic waves. Highly sensitive transducers are required to monitor the stress wave emission. The most common AE transducers are of the undamped piezoelectric type. These transducers exhibit high sensitivity about their resonant frequencies.

BACKGROUND

The application of AE instrumentation for monitoring hydraulic generated acoustic noise was demonstrated by Hutton (1) in 1969. Hutton investigated the detection of AE in the presence of hydraulic noise. During the study he made AE measurements of both cavitating and noncavitating flows. AE response due to cavitation noise was found to be significant at frequencies below 500 kHz. Signal levels for cavitating flow were in excess of 30 dB above the noncavitating flow.

Vaporous cavitating is the process by which cavities filled predominantly by water vapor form within the liquid. Cavitation bubbles form when local pressures decrease below the fluids' vapor pressure. When the bubbles again encounter pressures greater than vapor pressure the bubbles collapse. The bubble collapse occurs rapidly as the vapor within the bubble changes state to a liquid. The bubble collapse is followed by a rebound of a smaller bubble which then collapses in a cyclic decay pattern. The decay process emits shock waves into the surrounding fluid. Assuming the shock waves originate at a point the waves travel as an expanding spherical wave until intercepting a boundary.

Of particular importance in hydraulic structures are the flow conditions supporting the initiation of cavitation called inception or conversely the termination of cavitation termed desinence. Both terms relate to the change between cavitating and noncavitating flow. For the purposes herein, cavitation inception will be used as a general term referring to both inception and desinence. Flow conditions related to cavitation inception are defined by the cavitation index number,

$$\sigma = (Po - Pv)/0.5\rho Vo^2$$

where σ = cavitation index
Po = reference pressure
Pv = fluid vapor pressure
ρ = fluid density
Vo = reference velocity

DETERMINING CAVITATION INCEPTION

Monitoring acoustic noise is a common method of determining cavitation inception (1). Cavitation noise is characteristically broad band noise covering frequencies from a few kilohertz to megahertz. In contrast, the energy from background noise sources such as machinery and turbulent flow is mainly distributed at frequencies below 100 kHz. AE sensors with resonant frequencies above 100 kHz can be used to optimize the cavitation signal to noise ratio.

Threshold counting is a common signal processing technique implemented in AE testing. Threshold counting quantifies AE activity by counting the times the signal amplitude crosses a threshold value. Selecting a threshold value is largely one of experimentation. The threshold level must be chosen high enough to filter out background noise contamination to statistically acceptable levels.

Cavitation is studied by measuring AE counts per unit time as a function of the cavitaton index. Incipient cavitation is determined by a sharp drop in AE activity as evidenced by a change in the slope of the data. An example of AE data used to identify cavitation inception for a submerged jet-flow gate is given in figure 1.

LOCATION MEASUREMENTS

In addition to defining incipient cavitation, AE sensors can be used for locating and determining the distribution of near incipient cavitation activity. Location measurements of an AE event are made by measuring the time between the wave's arrival at different sensor locations. The location relative to two transducers is determined as,

$$L = [(T-\Delta T)/2T]*100 \qquad (1)$$

where, L = the distance from the nearest transducer to the event as a percent of the total distance between the transducers
T = total travel time of a wave between the transducers
ΔT = wave arrival time difference between the two transducers

Location measurements require the wave celerity between the sensors be known. In water where wave celerity varies as a function of air concentration, a rigid wave guide can be used between the sensors.

Wave guide design considerations for location measurements should include:

1. Wave speed. - A material with a high wave speed reduces the probability of false locations due to non-first arrival wave selection. If more than one signal reaches the wave guide within the time, T, false locations can occur. A false location is measured if during the travel time, ΔT, a new signal reaches the second sensor ahead of the original wave. A high wave speed between the sensors reduces the probability that a new signal will be received within time, T.

2. Signal attenuation. - The wave guide must transmit the signal with minor loss in amplitude. Location data can be biased toward the center of the wave guide if signal loss within the wave guide is significant. Signals received near the ends of the wave guide travel the greatest length and accumulate proportional losses

in amplitude. If a valid signal is attenuated within the wave guide to below the threshold level the signal is rejected. The data are then biased toward the location defined by minimum loss.

3. Planar wave propagation. - The wave guide should transmit all frequencies within the working passband as planar waves. Frequencies exciting the lowest mode of the wave guide travel straight down the wave gide at a constant wave speed. Signals at frequencies above the lowest cutoff frequency of higher modes can travel at angles to the axis of the wave guide.

4. Reflected signal amplitude. - Signal reflection at the ends of a wave guide should be minimized to prevent a reflection from being accepted as a valid signal. The reflection amplitude is a function of the angle of incidence at the wave guide sensor boundary. Often the reflected signal can be reduced by chamfering the ends of the wave guide.

At the Bureau of Reclamation Hydraulic Laboratory AE instrumentation was utilized to measure the streamwise distribution of cavitation downstream of a submerged fixed-cone valve, figure 2.

Under submerged conditions a strong eddy forms behind the downstream face of the valve. Cavitation first occurs in the shear layers of the annular jet.

To study the cavitation pattern a 0.15-m-diameter valve was tested in a low pressure water tunnel. The cavitation index could be varied by changing only the ambient pressure. Background AE levels from the noncavitating flow were measured to determine threshold settings.

Location measurements were made using matched 150 kHz resonant frequency AE sensors mounted on each end of a rigid wave guide. A 6.4-mm-diameter steel rod 0.4-m long was used as a wave guide. The steel rod had a planar wave speed measured at 4800 m/s. Signal loss over the length of the rod measured less than 0.5 percent.

The cutoff frequency for the first non-planar propagation mode of a cylindrical wave guide is given as,

$$\omega = 1.84\ C/R \tag{2}$$

where ω = angular cutoff frequency of the first nonplanar propagation mode
C = wave celerity
R = radius of the wave guide

From equation 2, signal frequencies below 443 kHz travel in the wave guide as planar waves.

The wave guide was tested to determine the end angle giving minimum signal reflection. A wave pulse generator was used for a signal source. End chamfers from 10° to 70° were tested to identify the angle of minimum wave reflection. Reflected signal amplitudes normalized by the amplitude of a 0° reflection are given in figure 3. From the test results it was determined a 31 percent reduction in the reflected wave amplitude could be obtained by chamfering the ends of the wave guide at 40°.

The wave guide was mounted in the streamwise direction at a radius of 0.15 m from the valve. Location data were measured for lightly cavitating flow. Data defining cavitation activity versus location were obtained at 10 percent increments of valve opening. The centroid of each distribution was used to define the position of cavitation inception, figure 4. The position of the inception point changed nearly proportional to eddy length. At 20 percent valve opening, the upstream movement of the cavitation is due to the start of cavitation on the valve seat. The reason for the sudden change in the location of cavitation inception at a 30 percent valve opening was not determined.

Eddy length was determined from velocities measured by laser doppler anemometer.

SUMMARY

Acoustic noise generated by cavitation bubble collapse can be easily detected by AE transducers. The high sensitivity and frequency response of AE transducers can enable them to monitor cavitation activity in areas where many other types of transducers would fail. AE signals can originate from both mechanics of solids and fluids. When AE transducers are used to monitor cavitation activity, measurements of background levels for noncavitating flow conditions are important.

REFERENCES

1. Hutton, P. H., "Acoustic Emission Detection in the Presence of Hydraulic Noise," Non-Destructive Testing, Vol. 2, pp. 111-115, May 1969.

2. Martin, C. S.; Veerabhadra, Rao P., "Application of Signal Analysis to Cavitation," International Symposium on Cavitation Noise," ASME Winter Annual Meeting, November 1982.

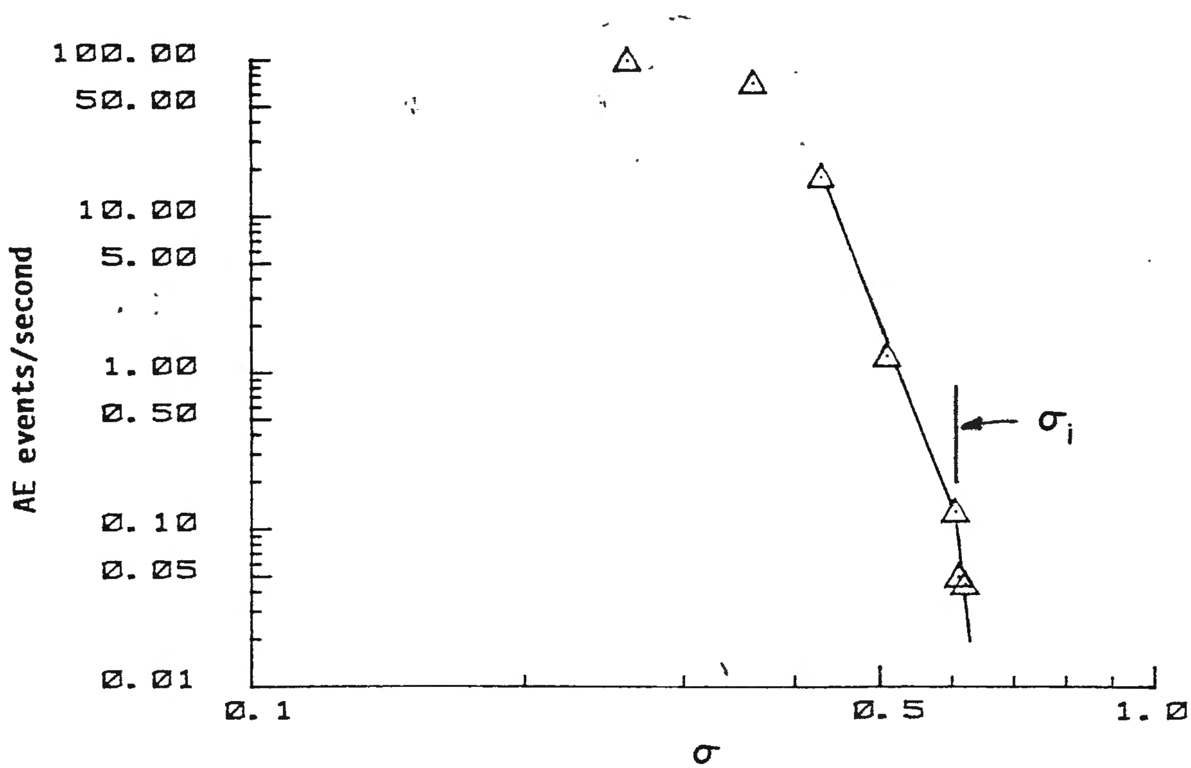

Figure 1. - Incipient cavitation defined by threshold counting.

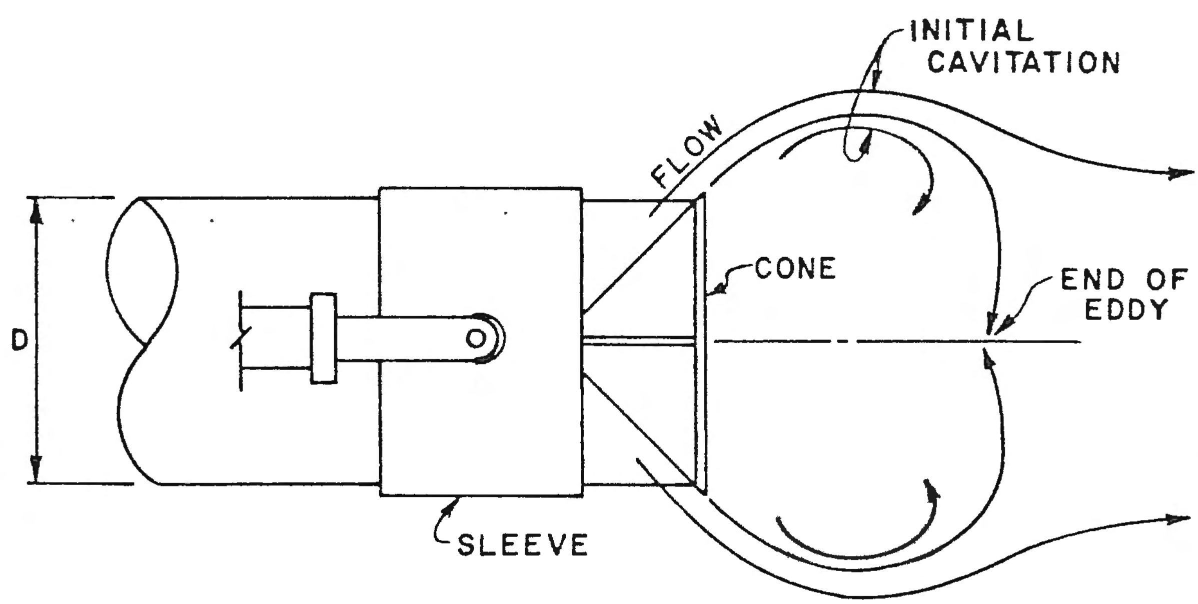

Figure 2. - Flow through a fixed-cone valve.

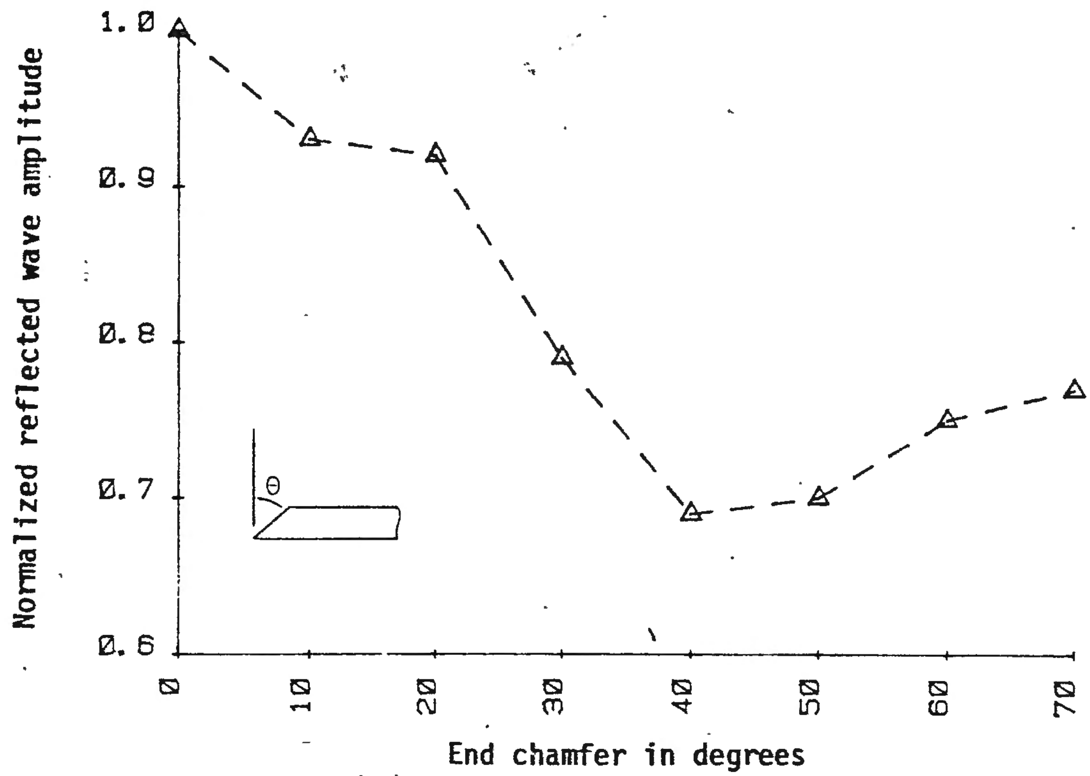

Figure 3. - Normalized reflected wave amplitude versus angle of incidence for a 6.4-mm-diameter steel rod coupled to an AE transducer.

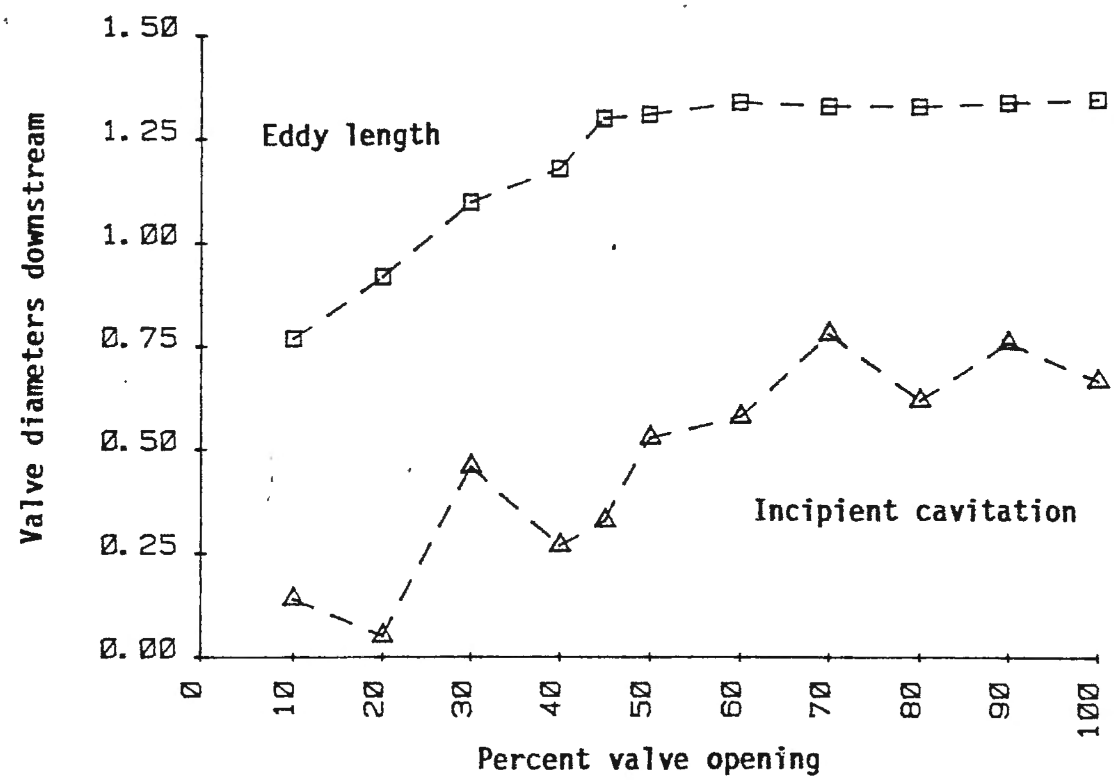

Figure 4. - Location of incipient cavitation for a submerged fixed-cone valve.