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Evaluation of the enhanced cavitation impact energy using a PVDF transducer with an acrylic resin backing

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ABSTRACT

A transducer using a PVDF (Polyvinylidene Fluoride) film as a pressure sensitive material has been developed and applied to evaluate the cavitation impact energy. However, enhanced cavitation impact used for peening destroys the PVDF film, which is directly exposed to the cavitation impact through a polyimide tape. In the present paper, a newly developed PVDF transducer is proposed, in which a PVDF film with an acrylic resin, which attenuates the burst signal, is put on the backside of a metallic base, where the front surface of the metallic base is exposed to the cavitation impact.

1. Introduction

Cavitation normally causes severe damage in hydraulic machinery, due to the powerful impact produced as bubbles collapse. In order to estimate cavitation erosion rate, it is very important to evaluate cavitation impact energy using even an indirect method [1]. In order to estimate the life time of hydraulic machinery against cavitation erosion it would be better to measure cavitation impact force directly. On the other hand, cavitation impact can be utilized for gettering silicon wafers [2,3] and surface modification of metallic materials [4–9]. In order to optimize the surface modification conditions, evaluation of the cavitation impact energy is required.

Measuring cavitation impact using a PVDF (Polyvinylidene Fluoride) film as a pressure sensitive material has been proposed [10–17], as the signal from a PVDF film is much clearer than that from a piezoelectric ceramic [18]. In using cavitation impact for surface modification, the cavitation impact induced by a high-speed water jet in water, i.e., a cavitating jet in water, can be enhanced by using a pressurized water chamber [5,6,8]. Soyama has also revealed that a cavitating jet in air is more effective than a cavitating jet in water [7,19]. Here, a cavitating jet in air was realized by injecting a high-speed water jet into a low-speed water jet, which was expelled into the air, using a concentric nozzle [7,19]. It is impossible to measure the cavitation impact induced by this enhanced cavitation jet, as the PVDF film, exposed to the cavitating jet through the polyimide tape, is destroyed. It is possible to measure the cavitation impact by putting the PVDF film on the backside of a metallic base, which is directly exposed to the cavitating jet. Because the pressure wave induced by the cavitation impact is attenuated and the PVDF is not broken. Namely, the strong cavitation impact can be measured by proposed transducer, even though previous transducer cannot measure the strong cavitation impact. However, the signal induced by a single impact in the PVDF film on the backside may cause a burst signal, i.e., a large number of signals from small to large amplitude similar to the signal from a ceramic piezoelectric transducer [18]. As both small and large cavitation impacts are produced randomly under the same cavitating conditions, the burst signal induced by a single impact should

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be attenuated by as much as possible in order to enable small cavitation impacts to be distinguished from the burst signal.

In this letter, in order to evaluate the enhanced cavitation impact energy, a new type of PVDF transducer is proposed. The proposed transducer was verified by measuring the relationship between the frequency and intensity of the cavitation impact and comparing the results with those of an established PVDF transducer for several weak cavitating conditions. The cavitation impact energy obtained using the proposed transducer was also used to examine the rate of erosion induced by the impact for several different conditions including severe ones. Note that this is the first report in which a PVDF transducer with an acrylic resin backing, which can measure enhanced cavitation impact, is proposed and verified.

2. Experimental facilities and procedures

In order to produce controlled cavitation impact, a cavitating jet apparatus was used [7,19]. The test water was pressurized by a plunger pump. The diameter of the nozzle for the high-speed water jet d_H was 0.8 mm and the diameter of the nozzle for the low-speed water jet d_L was 30 mm. To carry out erosion tests or to measure cavitation impact using the PVDF film transducer, specimens were exposed to the cavitating jet. From the measurement of admittance by an impedance analyzer, it has been revealed that the resonance frequency of PVDF sensor which is one of the piezoelectric sensors is over 10 MHz. The resonance frequency over 10 MHz means that the cavitation pulses with duration of μs can be measured. The injection pressure of the high-speed water jet p_1 and that of the low-speed water jet p_2 were varied to control the intensity of the cavitation impact. In this study, p_1 was set at 10, 15, 20, and 30 MPa, and p_2 was set to the value which gave the maximum erosion rate. In the present paper, the absolute pressure was used. The pressures of p_1 and p_2 were measured by pressure transducers. The injection pressure of the low-speed water jet p_2 was determined as Table 1 by the erosion test changing p_2 at various standoff distances as shown in the reference [7]. The reason why p_2 affects the cavitation intensity is follows. When p_2 is increased, the cavitation bubble collapses drastically as surrounding pressure of the cavitation bubble is high. At the same time, increase of p_2 decreases the cavitation impact, as the cavitating region becomes smaller because the pressure difference between p_1 and p_2 becomes small. The value of the standoff distance s was set to the maximum erosion rate obtained from a previous erosion test [7]. The specimens for the erosion test were pure aluminum (Japanese Industrial Standard JIS A1050), and the exposure time to the jet was 10 min. In the case of erosion induced by the cavitating jet, repeatability was about 3% [15].

Table 1
Erosion rate induced by cavitating jet in air.

Condition	p_1 (MPa)	p_2 (MPa)	s (mm)	E_R (mg/min)
I	10	0.16	35	4.14
II	15	0.16	40	13.70
III	20	0.19	45	29.76
IV	30	0.21	50	48.03

Fig. 1 illustrates two types of transducer, (a) a transducer of the established type, called a type A transducer, developed by Soyama et al. [13,15], and (b) the new type of transducer, called a type B transducer. Silver paste electrodes were attached to both sides of the PVDF film. Both type A and B transducers were exposed to the cavitating jet. In the case of type B, in order to attenuate the second and following pulses of the output signal, two layers of Kapton (polyimide) tape were attached on the front side, and an acrylic resin whose acoustic impedance is nearly equal to PVDF film was put on the back side of the film. The used Kapton tape had silicon-based glue. The thicknesses of the PVDF film, the Kapton tape, the stainless steel base and the block of acrylic resin were 110 μm, 60 μm, 20 mm and 40 mm, respectively. The type A transducer was calibrated using the pencil lead breaking method [13], as this method is appropriate for calibrating transducers for short duration pulses such as those produced by cavitation impact. However, in the case of the pencil lead breaking method, the induced force is very small. Thus, the type B transducer was calibrated using the steel ball dropping method [13]. The signal from the transducer was analyzed using an analog circuit to measure the pulse height distribution [13,15]. As several random pulses are induced simultaneously by cavitation impact, the number of pulses which were larger than a certain threshold was counted as the threshold level was changed, and the pulse height distribution, which is the relationship between the pulse amplitude and the frequency of occurrence, was obtained.

The impact energy E was calculated from the pulse height distribution as follows. Each impact energy E_i was calculated using the following formula:

$$E_i[\mathrm{J}] = I_i[\mathrm{J\ s^{-1}\ m^{-1}}]\tau_i[\mathrm{s}]A_i[\mathrm{m^2}] \quad (1)$$

I_i denotes the intensity of the sound power, τ_i denotes the pulse duration, and A_i denotes the effective area. The terms

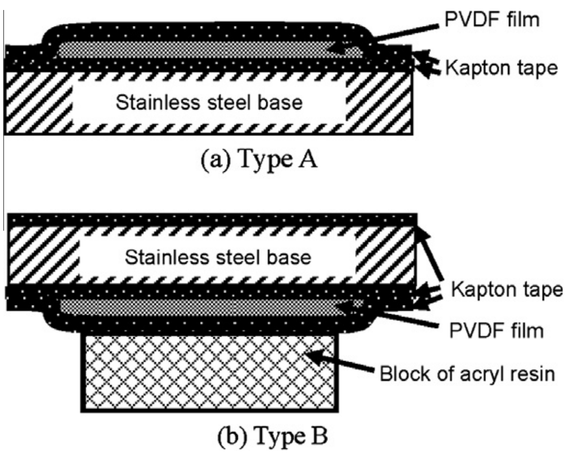

Fig. 1. Schematic diagram of the transducers.