Cavitation and Erosion in Submerged Water Jet

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This paper is concerned with cavitation and erosion in submerged water jet. Impulse force generated by cavitation bubbles in the jet is measured by an impulse force gauge. The accumulated count of impulse force per unit time is shown against the impulse force and the standoff distance from the nozzle exit. It is found that there are maxima in impulse force at two different standoff distances of 30 and 80, which are the values normalized by the nozzle diameter ($=1.5$ mm), and that the impulse force mainly appears in frequencies of a few Hz. Laser-microscopic observations show that erosion patterns on aluminum surfaces are classified into two ones.

[submerged water jet, cavitation, erosion, impulse force, impulse force gauge]

1. Introduction

It is important to make fundamental and systematic studies of cavitation and its active control in water jet nozzle and the water jet as well as structures of the nozzle and the jet in order to improve water jet technology on washing and debarring; augmentation of efficiencies, application to many kinds of materials, and reduction of costs.

One of key points for the improvement of water jet technology is to develop any small impulse pressure gauge which is suitable for the measurement of impulse pressures caused by the impingement of the water jet and by the collapse of cavitation bubbles. Until the present, commercially available pressure gauges and pressure-sensing papers accompanied with color change have been used for the measurement by the jet and the bubble collapse [1, 2]. They have, however, intrinsic defects in points that the gauges have fairly large sensing areas in comparison with minimum sizes of bubbles and that the papers cannot measure absolute values of pressures and detect variation in time of impulse pressures from bubbles.

In the present paper, a small impulse force gauge is devised [3], and the gauge is applied to measure impulse force by cavitation bubbles in submerged water jet. The gauge is here called impulse force gauge because it is calibrated in the unit of force. Cavitation erosion pits are also observed by a laser microscope.

2. Experimental Apparatus and Methods

Figure 1 shows the schematic diagram of submerged water jet which consists of horizontal triplex plunger pump, water treatment tank, and washing room. The size of washing room is: 1 m in length, 1 m in width, and 0.6 m in height. Water level is kept constant by an overflow pipe. A horn nozzle as shown in Fig. 2 is placed at 170 mm under the water surface. An impulse force gauge and a test piece are installed in one unit, and the unit can be moved by a 4-axes scalar type of robot. The surface of test piece is polished by emery paper and then alumina powder.

Fig. 1. Schematic diagram of submerged water jet machine.

Fig. 2. Horn nozzle.

Figure 3 shows the structure of the impulse force gauge which has been designed and produced by the present authors [3]. The gauge consists of a disc type of thin piezoelectric ceramic and two metal rods which have the same diameter and acoustic impedance as the ceramic; the material of the rods is titanium alloy. These materials are glued by electrically conductive resin. The right end of the rods (B) is machined in the conical shape with the vertical angle of 60 deg.

Fig. 3. Structure of impulse force gauge.

Compressive stress waves produced by the collapse of cavitation bubbles at the sensing area propagate through the boundaries of these materials without reflection, so that the form of the waves may not be disturbed by the boundaries. The waves are reflected at the right end with the conical shape and they are converted into diverging negative waves. The amplitude of the reflected negative waves decreases with the propagation distance from the apex, and the waves do not have large influences on gauge output when they return to the ceramic.

The rods with the ceramic are installed in an aluminum casing. Clearance between the rods and the casing is filled with silicon rubber to prevent from mechanical noises caused in the casing, and the rod (B) is fixed by an epoxy resin at the right end to prevent from axial vibration caused by impulse force.

3. Experimental Results and Discussion

Experiments are conducted under the condition : temperature = 10.7°C , high pressure = 7.1 MPa , ambient pressure of jet = 0.10 MPa , and cavitation number = 1.4×10^{-2} . Cavitation number is defined by $(p_2 - p_v) / (p_1 - p_2)$, where p_v is the saturated vapor pressure, p_1 the pressure of compressed water, and p_2 the ambient pressure of the jet. Cavitation is therefore in the state of sub-cavitation[4].

Figure 4 shows typical impulse force of submerged water jet cavitation. The abscissa denotes time, and the ordinate denotes force. The impulse force is found to be generated by the collapse of cavitation bubbles in the jet because the stagnation force of the jet is steady, therefore, it cannot be detected as the output of the gauge. Two pulses appear ; the first sharp and large pulse may be caused by the collapse of a cavitation cloud in the jet and the second small pulse by the second collapse after the rebound of the collapsed first one. The first pulse rises gradually for about $50\text{ }\mu\text{s}$ after its appearance, and it does steeply in a very short time. This behavior is characteristic of cavitation impulses[5]. Impulse pressure, which can be estimated from the measured force and

Fig. 4. Impulse force of submerged water jet cavitation.

the average area of erosion pits, is of the order of GPa.

Figure 5 shows the accumulated count of impulse force for 1 s against the force and the standoff distance. The standoff distance is normalized by the nozzle diameter (= 1.5 mm). It is found that (1) there are two maxima in the impulse force at the nondimensional standoff distances of 30 and 80, (2) the impulse force is mainly generated in frequencies of a few Hz.

The result (1) coincides with the well-known finding that there are two maxima in erosion at the nondimensional standoff distances of 30 and 80[6]. Concerning the result (2), however, the frequencies are very small compared with that of vortex ring cavitation around the jet [4]; the frequency of vortex ring cavitation can be estimated to be 308 Hz in the present condition, but no

Fig. 5. Accumulated count of impulse force against force and standoff distance.

Fig. 6. Classification of erosion patterns.

Table 1. Average diameter and depth of pits of Type I and Type II.

Type	Average pit diameter (μm)	Average pit depth (μm)
I	16.3	10.3
II	91.6	6.0

strong impulse force by vortex ring cavitation is observed.

Figures 6 (a) and (b) show typical profiles of cavitation erosion pits on the surface of aluminum test piece. Pit patterns are classified into two types, i. e., Types I and II, as shown in the figures. Pits of Type I are deep and narrow, and very symmetrical, on the other hand, pits of Type II are shallow and wide, and not so symmetrical in comparison with Type I.

Table 1 shows average diameter and average depth of pits of Types I and II at the nondimensional standoff distances of 30 and 80; these dimensions of pits are not dependent on the distances.

Figure 7 shows the numbers of pits in the area of $113.7 \text{ mm}^2 (= 1.9 \times 1.46 \text{ mm}^2 / \text{place} \times 41 \text{ places})$ and the ratios of Types I and II at the nondimensional distances of 30 and 80. These data were acquired for 1 s. It is found that pits at the distance of 30 are twice as many as those at the distance of 80 and that pits of more than 90 % at the both distances are composed of Type II.

4. Concluding Remarks

Cavitation phenomena in the submerged water jet have been studied by detecting the impulse force from cavitation bubbles and by observing erosion pits on material surfaces. The impulse force measurement has clarified that there are two maxima in the impulse force at the nondimensional standoff distances of 30 and 80 and that force is mainly given rise to at frequencies of a few Hz. No impulse force by vortex ring cavitation has been observed. Erosion patterns have been classified into two types depending upon area and depth of pits.

Fig. 7. Number of pits and ratio of Type I and Type II.

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