บันทึกข้อความ

ส่วนราชการ ภาควิชาวิศวกรรมเครื่องกล คณะวิศวกรรมศาสตร์ มหาวิทยาลัยอุบลราชธานี โทร ๓๓๐๙
ที่ ศธ 0529.8.4/พิเศษ **วันที่** ๑๑ ธันวาคม ๒๕๕๕
เรื่อง ขออนุมัติเงินสนับสนุนเพื่อนำเสนอบทความทางวิชาการในระดับนานาชาติ

เรียน รองคณบดีฝ่ายวิจัยและบริการ ผ่านหัวหน้าภาควิชาวิศวกรรมเครื่องกล

ด้วยข้าพเจ้า นายอนิรุตต์ มัทธุจักร์ ตำแหน่ง ผู้ช่วยศาสตราจารย์ สังกัดภาควิชาวิศวกรรมเครื่องกล คณะวิศวกรรมศาสตร์ มีความประสงค์ขออนุมัติเงินสนับสนุนเพื่อนำเสนอบทความทางวิชาการในระดับนานาชาติ เป็นจำนวนเงิน ๔๐,๐๐๐.- บาท (สี่หมื่นบาทถ้วน) ในการประชุมวิชาการระดับนานาชาติ " The 2nd International Conference on Engineering and Applied Science (2013 ICEAS)" โดยจะนำเสนอบทความวิชาการ ชื่อเรื่อง "Impact Pressure Measurement of High-Speed Liquid Jets" ซึ่งได้รับการตอบรับให้เข้าร่วมการนำเสนอโดยวาจาแล้วตามเอกสารที่แนบมาด้วยนี้

ทั้งนี้การนำเสนอผลงานจะมีขึ้นในระหว่างวันที่ ๑๕ – ๑๗ มีนาคม ๒๕๕๖ ณ ประเทศญี่ปุ่น พร้อมนี้ได้แนบสรุปรายละเอียดค่าใช้จ่าย เอกสารการตอบรับ หลักฐานการจัดประชุม และต้นฉบับบทความที่จะไปนำเสนอ

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(ดร.นันทวัฒน์ วีระยุทธ)
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เรียน รองคณบดีฝ่ายวิจัยและบริการวิชาการ

ตามที่ ผศ.ดร.อนิรุตต์ มัทธุจักร์ ได้ขอทุนสนับสนุนการนำเสนอผลงานวิชาการระดับนานาชาติ ในต่างประเทศ นั้น ได้ตรวจสอบเอกสารเบื้องต้นแล้ว เป็นไปตามเกณฑ์ที่ขอรับทุนทุกประการ จึงนำเรียน เพื่อขอที่ประชุม ERB ต่อไป

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<u>สรุปรายละเอียดค่าใช้จ่าย</u>

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The 2nd International Conference on Engineering and Applied Science (2013 ICEAS)

Paper ID: **ICEAS2013 – Paper 1035**
Title: **Impact Pressure Measurement of High-Speed Liquid Jets**
Author: **Anirut Matthujak**

Dear Author,

Thanks for your paper submission. On conclusion of the blindly review process, we are pleased to inform you that your paper is accepted for **Oral** presentation at the ICEAS 2013 in Tokyo on March 15 – March 17, 2013.

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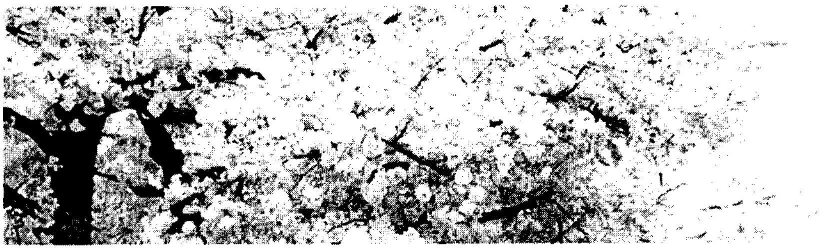

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Impact Pressure Measurement of High-Speed Liquid Jets

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Abstract

This study is to measure the impact pressure of high-speed water and diesel jets at various stand-off distances from the nozzle exit. The high-speed liquid jets are generated by the impact of a projectile, which known as impact driven method, launched by a horizontal single-stage gas gun. The impact pressures of the jets were measured by the PVDF pressure sensor. Moreover, they were calculated from the water-hammer equation in order to compare with the measurement. From the measurement and calculation, it was found that the impact pressure of water and diesel jets calculated from water-hammer equation decreases gradually, while that measured by the PVDF pressure sensor decreases exponentially as the stand-off distance increases. The impact pressures measured by the pressure sensor and calculated from water-hammer equation are different because the water-hammer equation does not consider the effects of atomization, vaporization and break-up of the jet, being the normal phenomena of the high-speed liquid jet.

Keyword: Impact pressure, High-speed liquid jets, Impact driven method, PVDF pressure sensor

1. Introduction

It is known well that the impact of high-speed liquid jet can cause damage or permanently deform of structure materials. If the high-speed jet strikes on solid surface, it can generate a great number of pressures on solid surface. This pressure causes stresses, which can create damage in material. Such damage can occur on the surface of aircraft during high-speed flight in rain, steam turbine blades, surface cleaning, fuel injection part, etc [1, 2]. Therefore, the study of high-speed liquid jet impact on surface has been interested in wide range of technology, such as jet cleaning and cutting technology, mining and tunneling [3, 4]. Recently, the jet impact has gained attention in medical applications, such as the drug injection, the tissue cutting, and the removing of a cerebral thrombus [5].

In 1961, F.P. Bowden et al. [6] studied the deformation of solid by the impact of a water jet on the solid surface. It was found that there were five general types of deformation produced in the solid. There were: (i) circumferential surface fractures, (ii) subsurface flow and fractures, (iii) large-scale plastic deformation, (iv) shear deformation around the periphery the impact zone and (v) fracture due to the reflexion of stress wave. After that in 1966, J.H. Brunton [7] generated water jet at speed up to 1,200 m/s to investigate the mode of deformation in brittle and plastically deforming material. It was found that the predominating mechanism of deformation depended on mechanical properties of the solid and the impact velocity of jet.

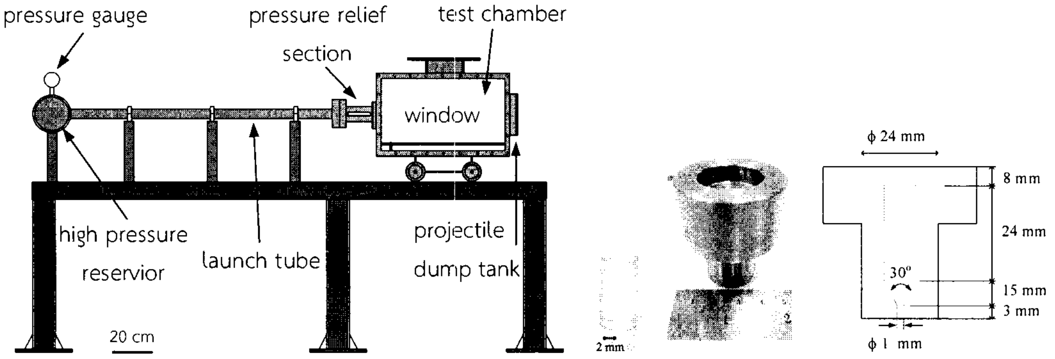
From the previous literature reviews [1-7], the studies of high-speed liquid jet impact on a solid surface have been focused on the investigation of the damage out across the surface, the calculation of water-hammer pressure for 2-3 time speed of sound and the impact pressure measurement of water jet only. However, the impact pressure measurement of high-speed liquid jet is still difficult because of the limitation pressure transducer.

In this study, the impact pressures of water and diesel jets at various stand-off distances from nozzle exit were measured by the PVDF pressure sensor, which was specially designed and developed for this experiment. The values of impact pressure found from the PVDF pressure sensor with that calculated from water-hammer equation were compared.

2. Experiments

2.1 Jet generation

In this study, high-speed liquid jets are generated by impact driven method [6, 7]. Using this technique, the liquid retained inside the nozzle cavity is impacted by a high-speed projectile. The liquid obtains the momentum transfer from the projectile and is injected from the nozzle. The high-speed projectile in this technique has been generated by the Horizontal Single-Stage Gas Gun (HSSGG) as shown in Fig. 1a. The HSSGG consists of high pressure reservoir, launch tube, pressure relief section and test chamber. The high pressure reservoir has an inside diameter of 7.62 cm and length of 21 cm which its volume is 9.58 x 10^{-4} m^3. The launch tube has a inside diameter of 10 mm and length of 1.1 m. The pressure relief section has a length of 15 cm, which is designed to diminish the blast wave in front of the projectile. The pressure relief section has 3 rows of holes; which each row has 4 holes having a diameter of 5 mm. The test chamber is a square tank of 40 x 50 cm in width and 60 cm in length with Polymethyl Methacrylate (PMMA) windows on two sides for visualization. The projectile is made of Polymethyl Methacrylate (PMMA), is cylindrical shape with diameter of 9.5 mm, 15 mm in length and its weight is 1.15 g as shown in Fig. 1b. This HSSGG has been employed to generate the projectile velocity ranged from 50 to 250 m/s in each driving pressure. The nozzle connected to pressure relief section is made of mid-steel, and its dimension is shown in Fig. 1c. The projectile velocity of about 220 m/s was used in all experiments. Its velocity was generated by driving pressure of 8 bars.



(a) (b) (c)

Fig. 1 (a) Horizontal Single-Stage Gas Gun, (b) projectile and (c) Nozzle geometry

2.2 Impact pressure measurement

The high-speed liquid jets generated by HSSGG are impulsive jet. Once the jet impacts on solid surface, the impact pressure reaches a high value in a very short time. This pressure is dynamics pressure or water-hammer pressure created by impact of impulsive jet. This dynamics pressure is a pressure of the high MPa up to GPa range. Hence, it is not possible to measure it by conventional instrumentation.

To measure these high pressures, the pressure sensor was designed, manufactured and calibrated. The pressure sensor is constructed with Polyvinylidence Fluoride (PVDF) piezoelectric film, a 6 mm thick of PMMA and a 8 mm thick rubber support. It is assembled in 8 mm thick housing with an outer diameter 75 mm as shown in Fig 2. This PVDF film is a flexible component which comprises a 28 μm thick of PVDF polymer piezoelectric film with screen printed Ag-ink electrodes.

The experimental setup for measuring the impact pressure of liquid jets by a PVDF is shown in Fig. 2. Once the liquid jet impacts on the PMMA surface, the PVDF film will respond to impact pressure giving a pressure signal that is recorded by oscilloscope as shown in Fig. 3. In the experiment, the stand-off distance from nozzle exit to the PVDF pressure sensor is varied changed by adjusting the pressure sensor holder backwards or forwards.

Figure 3 shows a load-time trace for a water jet impact at 4 cm stand-off distance from the nozzle exit. This is the pressure signal from oscilloscope in voltage signal. The voltage signal can be calculated to be pressure signal by the equation (1), being calibrated and reported by W. Sittiwong et al. [8].

$$P = (17{,}975V - 2{,}614.4) \times (6.894757 \times 10^{-3}) \qquad (1)$$

Where P is the impact pressure of the jet (MPa) and V is voltage signal from PVDF pressure sensor (Voltage).

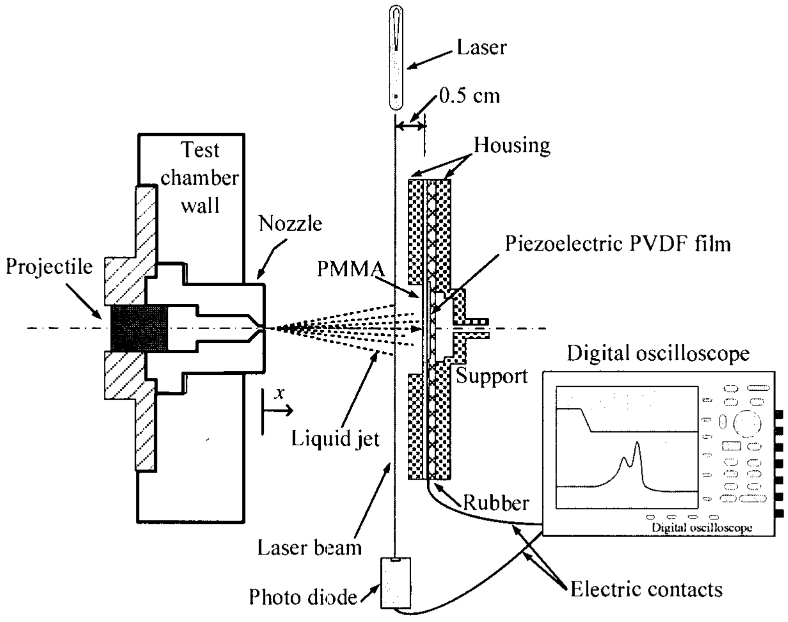


Fig. 2 Experimental setup for impact pressure and jet velocity measurement

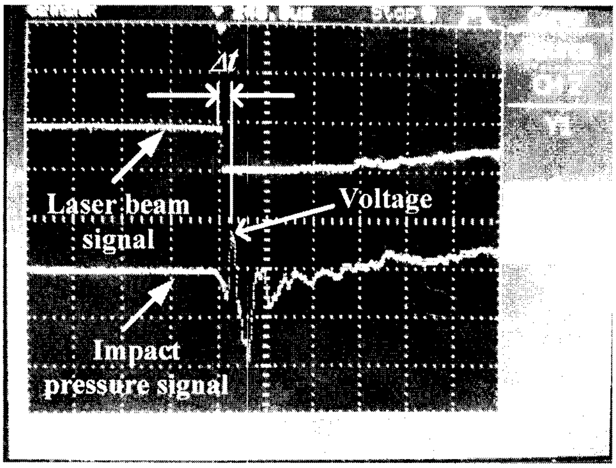


Fig. 3 A load-time trace for a water jet impact at 4 cm stand-off distance

2.3 Jet velocity measurement

In this experiment, the jet velocity was measured by laser beam interruption method. A diode laser beams cross perpendicularly to the jet path in the test chamber as shown in Fig. 2. The laser beam was placed at 5 mm in front of the PVDF pressure sensor in all experiments. When the jet tip interrupted laser beams and the jet impacted on the pressure sensor, the corresponding output signals were recorded and displayed in a digital oscilloscope. The jet travelling duration time was measured by an oscilloscope as shown in Fig. 3. From the time interval between the laser beam signal with the impact pressure signal (Δt) in Fig. 3, the jet velocities (V_j) can be calculated by:

$$V_j = \frac{\Delta s}{\Delta t} \quad (2)$$

Where Δs is the distances between laser beams and the pressure sensor and Δt is the time interval of the jet over the distance Δs.

This measurement technique of impact pressure of the jets and jet velocity is specially designed and developed for this study. Both the impact pressure and the jet velocity being used for calculating the impact pressure in water-hammer equation can be obtained at the same time, which is the advantage of this technique. Therefore, the value of impact pressure found from the PVDF pressure sensor can be reasonably compared with that determined from water-hammer equation.

3. Water-hammer effect

When a droplet of liquid crash on a rigid surface under higher velocity or the frontal liquid in column is stopped instantaneously and sideways flow is prevented. In these cases, the pressure developed in moving column or the high pressure occur in liquid impact as a result of the water-hammer effect. The water-hammer pressure for a liquid striking a rigid surface is given by the equation [3, 6, 7].

$$P = \rho C V_j \quad (3)$$

Where P is the impact pressure of the jet (Pa), ρ is the density of the liquid jet (kg/m^3), C is the sound speed of the liquid jet (m/s) and V_j is the jet velocity or impact velocity (m/s).

Table 1 Properties of liquids used in the experiment

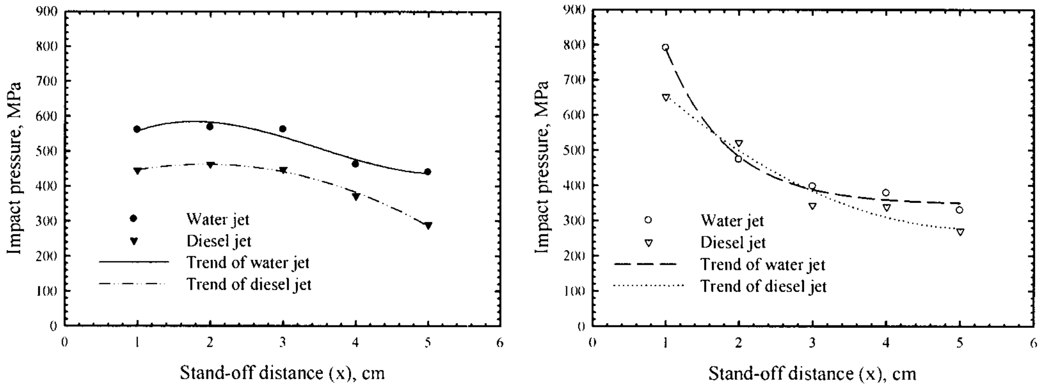
Liquid type	**Formula**	**Molecular weight (g/mol)**	**Density at 20^{0}C (kg/m^3)**	**Speed of sound at 20^{0}C (m/s)**	**Kinematics viscosity at 20^{0}C (cSt)**	**Surface tension at 20^{0}C (N/m)**
Water	H_2O	18	998	1,483	1.003	0.0728
Diesel	$C_{14}H_{30}$	198	840	1,350	1.8 - 4.0	0.0244

The water-hammer equation can be used for calculating the maximum pressure being developed when a jet impinges on a rigid surface. The density and the sound speed of water and diesel jets used for calculating in the water-hammer equation can be found in Table 1.

4. Results and discussion

Figure 4 shows comparison between the impact pressures of high-speed water jet and diesel jet at 1, 2, 3, 4 and 5 cm stand-off distance from nozzle exit. Experiments were repeated three times at each individual positions. The scatter of data points is reasonably small. The impact pressures were calculated from water-hammer equation as shown in Fit. 4a. The impact pressure decreases gradually to approximately 561.1 MPa and 444.9 MPa at x = 1 cm, down to 440.2 MPa and 289.8 MPa at x = 5 cm for the water and diesel jets, respectively. This is because the velocity of both water and diesel jets, being used for calculating in water-hammer equation, decreases as the stand-off distance increases, which is the normal phenomena of the high-speed jet injected in air [8]. The impact pressures of diesel jet are lower than that of water jet at all stand-off distances. This is because the density and sound speed of diesel are lower than those of water as shown in Table 1, while the velocity of both jets at each stand-off distance is not much different. Figure 4b shows the impact pressure measured by the PVDF pressure sensor. The impact pressure decreases exponentially to approximately 790.8 MPa and 651.2 MPa at x = 1 cm, down to 328.6 MPa and 269.5 MPa at x = 5 cm for the water and diesel jets, respectively. This is because the atomization, vaporization and breakup of both jets increase as the stand-off distance increases as described by A.Matthujak et al. [8]. The impact pressures of water and diesel jets measured by the PVDF sensor are not much different at each stand-off distance.

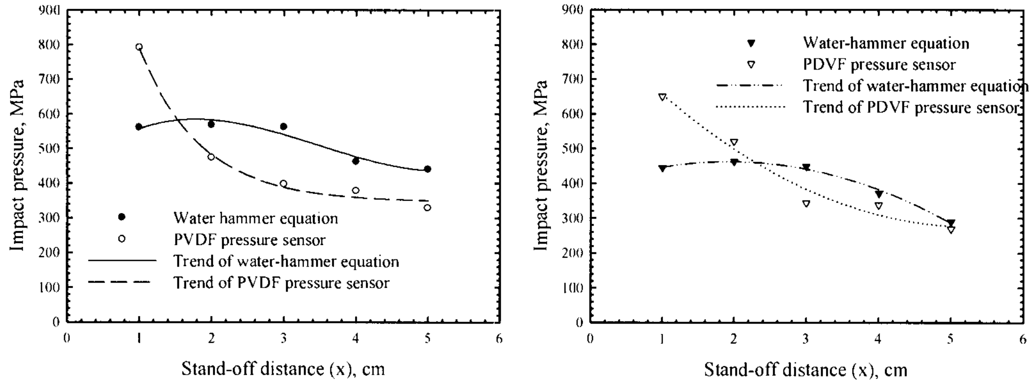
Figure 5 shows comparison between the impact pressures of high-speed water and diesel jets found from water-hammer equation and PVDF pressure sensor at stand-off distance from nozzle exit. The impact pressure of water and diesel jets measured by the PVDF pressure sensor is higher than that the water-hammer equation at the stand-off distance of 1 and 2 cm as shown in Fig. 5a-5b, respectively. After those stand-off distances onwards, the impact pressures of water and diesel jets measured by the PVDF pressure sensor are lower than those the water-hammer equation. From comparison, the values of the impact pressure found from the measurement and the calculation are much different at all stand-off distances. This may imply that the normal phenomena of high-speed liquid jet injected in air [8], being atomization, vaporization and break-up of liquid jet, importantly effect on the impact pressure of the impact-driven high-speed liquid jet injected from a single hole nozzle, while the water-hammer equation does not consider these effects.



(a) water hammer equation

(b) PVDF pressure sensor

Fig. 4 Comparison between the impact pressures of high-speed water and diesel jets at stand-off distance from nozzle exit



(a) water jet

(b) diesel jet

Fig. 5 Comparison between the impact pressures of high-speed liquid jets found from water-hammer equation and PVDF pressure sensor at stand-off distance from nozzle exit

5. Concluding remarks

A horizontal single-stage gas gun (HSSGG) was designed and manufactured for high-speed liquid jet generation. The impact pressure of high-speed water and diesel jets injected in air at five stand-off distances from the nozzle exit were measured by the PVDF pressure sensor. Moreover, the jet velocity of both jets could be measured for calculating the impact pressure in the water-hammer equation at the same time, which this technique is specially designed and developed for this study. The maximum impact pressure of water and diesel jets is 790.8 MPa and 651.2 MPa at x = 1 cm from the measurement and 561.1 MPa and 444.9 MPa at x = 1 cm from the calculation. Since the water-hammer equation does not consider the effect of jet phenomena, the impact pressure calculated from water-hammer equation and measured by the pressure sensor are much different. Therefore, the improvement of water-hammer equation for the impact-driven high-speed liquid jet injected from the single hole of the nozzle should be done in the further study.

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