The 10th JFPS International Symposium on Fluid Power FUKUOKA 2017 Oct. 24-27, 2017 JFPS The Japan Fluid Power System Society

# FLOW VISUALIZATION OF CAVITATION JET USING HIGH-SPEED CAMERA

Ryosuke FUNACHI*, Sayako SAKAMA** and Yutaka TANAKA***

* Major in Engineering and Design, Graduate School of Engineering and Design, Hosei University
2-17-1 Fujimi, Chiyoda-ku, Tokyo, 102-8160 Japan
(E-mail: ryosuke.funachi.2d@stu.hosei.ac.jp)
** Department of Mechanical Engineering, College of Science and Engineering, Aoyama Gakuin University
5-10-1 Fuchinobe, Chuo-ku, Sagamihara-shi, Kanagawa, 252-5258 Japan
(E-mail: sakama@me.aoyama.ac.jp)
*** Department of Engineering and Design, Faculty of Engineering and Design, Hosei University
2-17-1 Fujimi, Chiyoda-ku, Tokyo, 102-8160 Japan
(E-mail: y_tanaka@hosei.ac.jp)

**Abstract.** Recently, hydraulic systems are required to be smaller and have higher output. However, the working pressure of the hydraulic system is rising, and as a result, the occurrence of cavitation which causes various serious problems such as cavitation bolstering is promoted. The purpose of this study is to remove air bubbles generated by cavitation from hydraulic oils and solve the problems of hydraulic systems derived from the air bubbles. In this paper, in order to know the state of bubbles caused by cavitation, we experimentally investigate the behavior of the cavitation jet through a cylindrical nozzle by recording the motion of the cavitation jet with a high speed camera. As a result, it is confirmed that cavitation is intermittent with high speed phenomenon and many bubble diameters generated by the cavitation are less than 0.1 mm. The average break out frequency of the cavitation jet is about 8 kHz. The separated bubbles collapsed, change to the fine bubbles, and returned to the reservoir. We conclude that the bubble removal system is necessary for hydraulic system to eliminate the minute bubbles.

**Keywords:** Cavitation, Entrained Air, Flow Visualization, High Speed Camera, Hydraulic System

## INTORODUCTION

The rated pressure of hydraulic equipment installed in construction machines has been increased over the past several decades, and required to be smaller and lighter in order to improve workability. Figure 1 shows the change of rated pressure and power density from 1975 to 2011 for typical construction machinery. Between

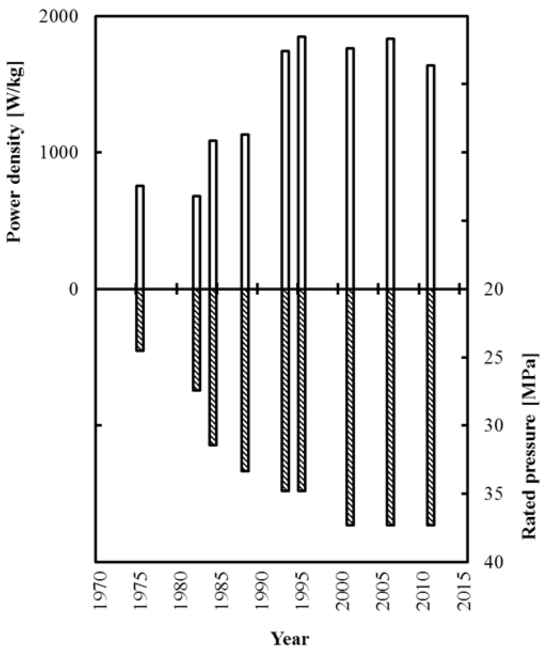


**FIGURE 1.** Power density and rated pressure of the construction machinery

1975 and 2011, the rated pressure of hydraulic pump increased about 1.5 times and the power density increased about 2.5 times. In recent years, further miniaturization is required in order to deal with the designation system of exhaust gas countermeasure type of construction machineries. Therefore, it is expected that the rated pressure will further increase in the future.
The high pressure of the hydraulic system makes it possible to miniaturize hydraulic equipment, but there are various problems. One of the problems is to promote the occurrence of cavitation. About 8 to 10% of the air is dissolved in the working oil under atmospheric pressure, and dissolved air greatly affects the occurrence of cavitation. Cavitation jets are generated when the pressure drops suddenly at the narrow flow path such as notches in the pump, valve orifice parts, etc. Cavitation bubbles precipitated with cavitation jets collide against the walls of the equipment and erode them [1]. In addition, air bubbles precipitated by cavitation continue to dissolve in the oil, causing degradation of the dynamic characteristics of the equipment [2] or promoting deterioration of hydraulic oil [3].
The purpose of this research is to solve the problem of hydraulic system caused by air bubbles by eliminating air bubbles in hydraulic oil. In order to efficiently eliminate air bubbles in the oil, the condition of the air bubble should be known in detail. In this paper, the state of the cavitation jet is experimentally visualized using a high speed camera, and the state and inception of the cavitation is analyzed by a series picture images.

## EXPERIMENTAL METHODS

Figure 2 shows a schematic diagram of experimental hydraulic circuit. Air bubbles are intentionally infused into working oil at a suction line of a pump. A hydraulic chamber which can generate the cavitation jet is attached between A and B in the hydraulic circuit. Figure 3 shows a sectional view of the chamber which is the cavitation generation part. After pressurized oil is rapidly decompressed through a cylindrical choke, a jet with cavitation is flowing out from a cylindrical choke. A transparency observation window made by acrylic resin is attached to the side of the chamber, and it is possible to observe the state of the flow inside the chamber. In this experiment, the state of the jet flowing out from the cylindrical choke is digitally recorded and stored with a high-speed digital camera through the observation window. Figure 4 shows a typical example of flow visualization of cavitation jet by the digital camera.
In this experiment, a mineral-based hydraulic fluid with a kinematic viscosity of 31.65 $mm^2/s$ (@ 40 °C) is used. The oil temperature in the reservoir at the time of the experiment is kept at 47°C. An oxygen meter in the reservoir stood at 6.5 mg / L.
An upstream pressure of the chamber was kept at 20 MPa and a downstream pressure was 0.2 MPa. A cavitation number at this time was $1.1 \times 10^{-2}$. A volume flow rate measured with a flow meter attached to the downstream

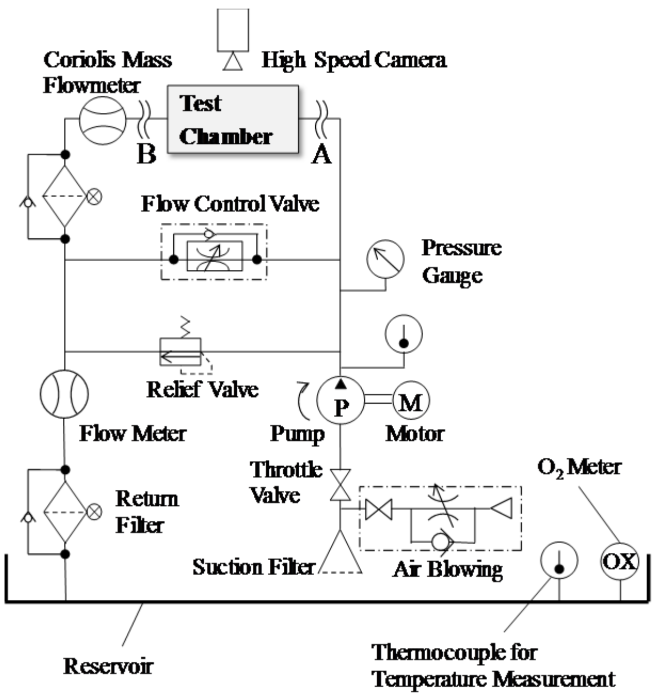


**FIGURE 2.** Hydraulic circuit of test apparatus



 

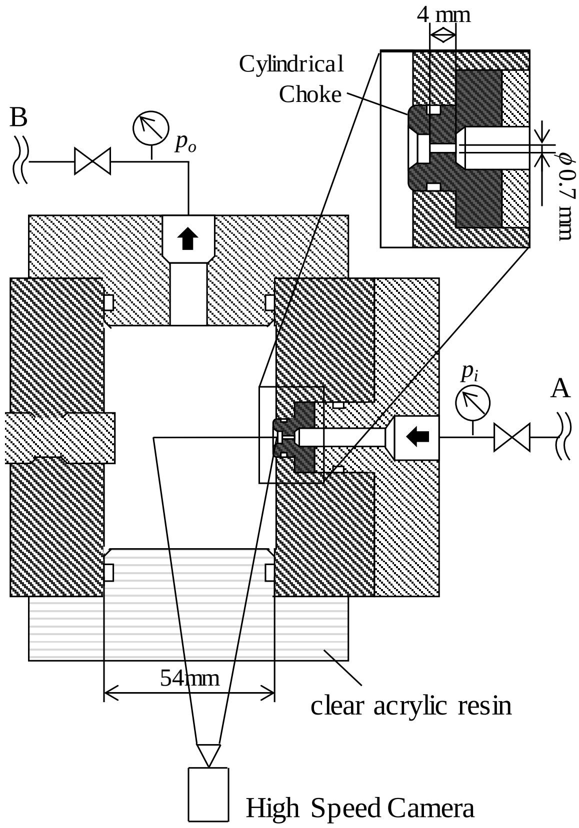


**FIGURE 3.** Schematic of the test chamber for flow visualization of the cavitation jet

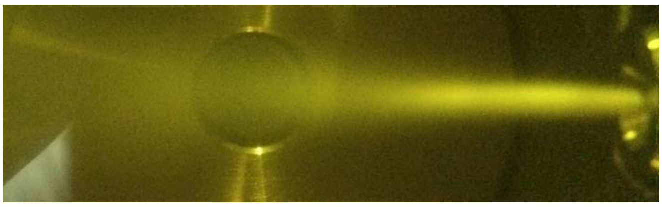

**FIGURE 4.** Flow visualization example of the cavitation jet with digital camera

side of the chamber is 1.66 L/min. And the average flow velocity of the fluid passing through the choke is 72 m/s. Cavitation jets from the outlet of the cylindrical choke to the downstream side were digitally recorded and stored at $1\times10^5$ frame/s using the high speed digital camera (FASTCAM SA-Z).

## EXPERIMENTAL RESULTS

Figure 5 shows the series digital images of the cavitation jets for every 3 frames ($3.0\times10^{-5}$ s). The outlet of the cylindrical choke locates on the right side of the each image, and the jet flow with cavitation bubbles flows toward the left side of the each image. The image indicated by white color is a bubble body occurred by cavitation.

It can be confirmed that the large bubble body having a diameter of 5 mm or more are repeatedly separated out by passing through the cylindrical choke and the separation of air by the cavitation is an intermittent phenomenon. The state of the cavitation inception is analyzed for 1000 frames ($1.0\times10^{-2}$ s). The bubbles separate out about every $1.0\times10^{-4}$ seconds and 76 large bubble bodies separate out during $1.0\times10^{-2}$ seconds.



 

Figure 6 shows a histogram of the bubble inception frequency calculated from the bubble inception cycle. The bubble inception frequency is 5 to 13 kHz, and the average frequency is 8.0 kHz. The cavitation often generates with noise. It is inferred that the noise sounds in this frequency band are generated when the cavitation occurs. Large bubble bodies by the cavitation collapse at 25 mm downstream side of the outlet of the cylindrical choke, and it turns out that it flows into the downstream direction as fine bubbles. It is confirmed that the diameter of the bubbles is about 0.1 to 0.2 mm and most of the bubbles are smaller than 0.1 mm. In hydraulic systems, actually, when small bubbles separated out by the cavitation return to the reservoir, it is difficult to eliminate the bubbles in a short time [4]. In hydraulic systems where generation of cavitation is conspicuous, it is necessary to introduce a bubble removal system capable of removing fine bubbles.

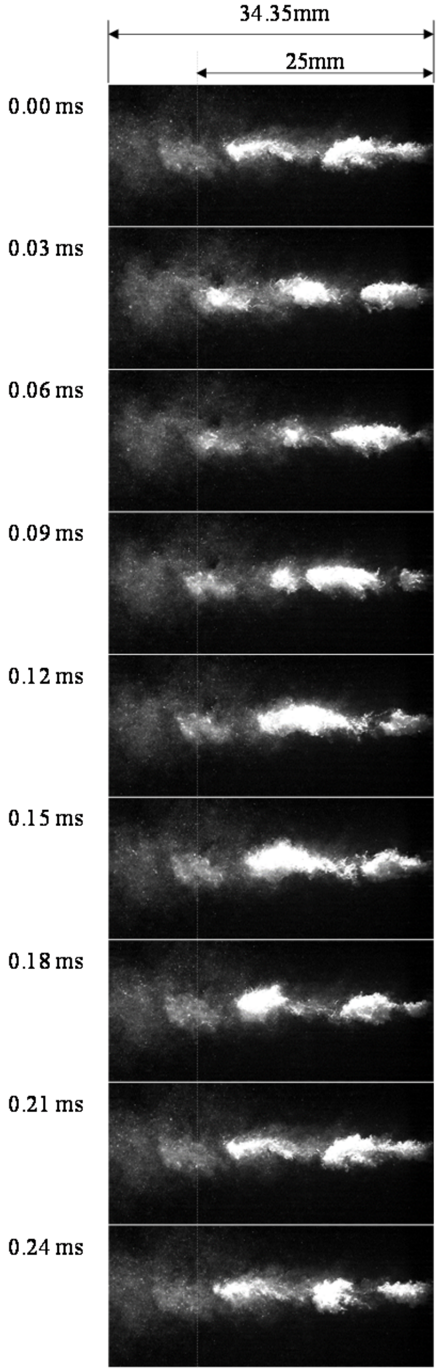


**FIGURE 5.** Flow visualization of the cavitation jet with high-speed camera

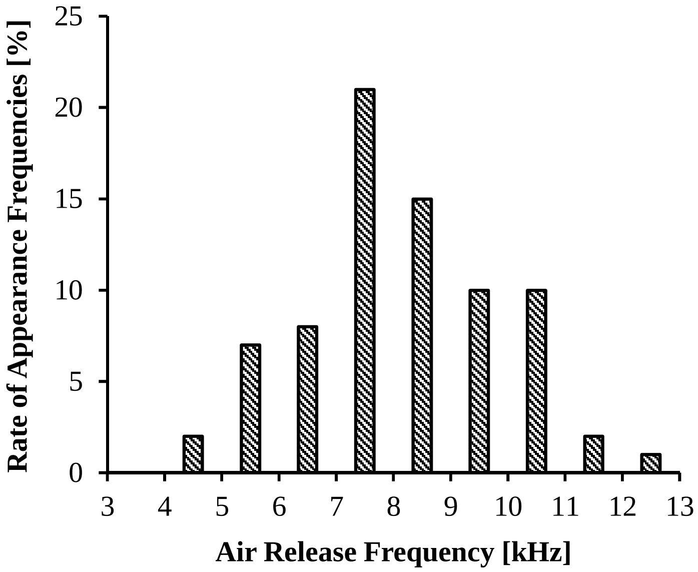


**FIGURE 6.** Air release frequency of the cavitation

# CONCLUSIONS

In this report, the state of occurrence of cavitation jet in the hydraulic circuit is experimentally recorded using the high speed camera and the phenomenon is analyzed in detail. As a result, it is confirmed that cavitation is intermittent with high speed phenomenon. The average break out frequency of the cavitation jet is about 8 kHz. The separated bubbles collapsed, change to the fine bubbles, and returned to the reservoir. The bubble removal system is necessary for hydraulic system to eliminate the minute bubbles.

# ACKNOWLEDGMENTS

Utilization of the high-speed camera is supported by the cooperation of Photron Corporation. We express appreciation the technical staff, Mr. Takashi Tanaka of Photron Corporation. In addition, this research was supported by the Fluid Power Technology Promotion Foundation, the JSPS KAKENHI Grant Number 259669, 26420086, and a grant-in-aid from the Ministry of Economy, Trade and Industry, Japan.

# REFERENCES

1. Knapp, T.T., Daily, J.W. and Hammitt, F.G, Cavitation, McGraw-Hill, (1970).
2. Ericson, L. and Palmberg, J. O. : Measurement of Free Air in the Oil Close to a Hydraulic Pump, Proc. of the 7th JFPS International Symposium on Fluid Power, 647/652, (2008).
3. Backe, W. and Lipphardt, P. : Influence of the Dispersed Air on the Pressure, CI Mech. Eng., C97-76, 77/84, (1976).
4. Ida, T, Drag Coefficients of Single Gas Bubbles Rising in Hydraulic Fluids, Trans. Hydraulics and Pneumatics, Vol.9, No.4, pp.261-269, (1978), (in Japanese).



 