Mechanism of the Shock Wave Generation and Energy Efficiency by Underwater Discharge

Osamu Higa[1], Ryo Matsubara[2], Katsuya Higa[2], Yoshitaka Miyafuji[1], Takashi Gushi[1], Yukimasa Omine[1], Kazuyuki Naha[3], Ken Shimojima[3], Hiroshi Fukuoka[4], Hironori Maehara[5], Shigeru Tanaka[5], Takumi Matsui[2] and Shigeru Itoh[6]

[1]Technical Support Section, Okinawa National College of Technology, 905 Henoko, Nago, Okinawa 905-2192, Japan

[2]Department of Information And Communication System Engineering, Okinawa National College of Technology, 905 Henoko, Nago, Okinawa 905-2192, Japan

[3]Department of Mechanical System Engineering, Okinawa National College of Technology, 905 Henoko, Nago, Okinawa 905-2192, Japan

[4]Department of Mechanical System Engineering, Nara National College of Technology, 22 Yata-cho, Yamatokoriyama city, Nara 639-1080, Japan

[5]Shock Wave and Condensed Matter Research Center, Kumamoto University, 2-39-1 Kurokami, Kumamoto City, Kumamoto 860-8555, Japan

[6]Okinawa National College of Technology, 905 Henoko, Nago, Okinawa 905-2192, Japan

E-mail: osamu@okinawa-ct.ac.jp

ABSTRACT

We are developing the rice powder manufacturing system using an underwater shock wave. The purpose of this study is to research a mechanism of the shock wave generation and energy efficiency by underwater discharge in order to increase energy of the underwater shock wave. We observed the shock wave generation using the visualization device with a high speed camera, and measured voltage current characteristics at the same time. As a result, it was clarified that countless underwater shock waves were generated at the time of water plasma expansion by discharge. But, the shock wave was not confirmed at the time of after a second peak of the damping oscillation. It was clarified that one part of charging energy was used to generation of the shock wave. Therefore, it was clarified that to release energy by the critical oscillation is desirable for efficient generation of the shock wave.

Keywords: Underwater Shock Wave, Underwater Discharge, Rice Powder, Damped Oscillation

1. INTRODUCTION

In Japan, food culture became to like western. Many foods are imported from overseas. The food self-sufficiency was decreased to 39% at 2012. Ministry of Agriculture, Forestry and Fisheries of Japan was promoting a national movement “FOOD ACTION NIPPON”[1]. In this situation, Japanese people are interested in the rice powder made from a rice of main food in Japan, it have been expected to be used alternative food of flour. But, due to the higher manufacturing cost of a rice powder, it is not so popular. It is known that the pulse power have been widely research, it can be use high energy by to compress charging energy in a moment [2]. A generation and using of a shock wave by discharge is one of them. A shock wave generated by underwater discharge has the energy higher than in air. We have been developing the rice powder manufacturing system using underwater shock wave, it is expected to be made the rice powder with low cost [3]. A shock wave is separated to a penetration wave and a reflection wave by different density when a shock wave passes through a rice grain. In this time, a shock wave pulls outside of a rice grain, a rice surface is crashed [4]. It is called a spall-fracture. A mechanism of that a rice is crashed by a spall-fracture is showed Fig.1. Usually, a rice grain is very hard so that a high energy is needed to crash a rice grain.

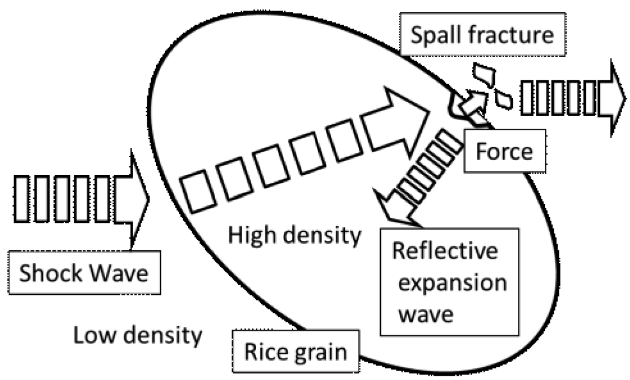


Figure 1. The mechanism of spall fracture by the underwater shockwave

2. EXPERIMENTAL APPARATUS AND PROCEDURES

2.1 TWO PRESSURE VESSELS FOR VISUALIZATION SHOCK WAVE AND DISCHARGE PHENOMENON

Fig.2 shows two pressure vessels for visualization. Vessel A is made to investigate effect of breakdown by water flow in a vessel. In this vessel, water has flowed inside the vessel from the top to the bottom holes, a water flow around the electrode is rectified by a current plate. The vessel made by aluminum has an internal diameter of 50mm wide, of 160mm height and of 50mm depth. Two electrodes which were made by capper with 5mm cylindrical were set to center of the vessel. It is covered by polycarbonate plate of 20mm thickness. We can observe electric discharge phenomenon. Vessel B was made for to investigate the convergence of the shock wave by oval shape in 2 dimensions. Two electrodes are set at the position of first focus point of oval, It can observe that the shock wave generated by underwater discharge focus to the second focus point. The vessel made by aluminum, and the configuration of the oval shape has respective by a short side of 160mm, a long side of 167.7mm, and a depth of 30mm. The distance between focuses is 50mm. The two electrodes have been held by an insulating material, which is a diameter of 20mm cylindrical copper. The front and rear of the vessel have been open. When we observe the shock wave, the vessel is overwhelmed in water of the acrylic tank.

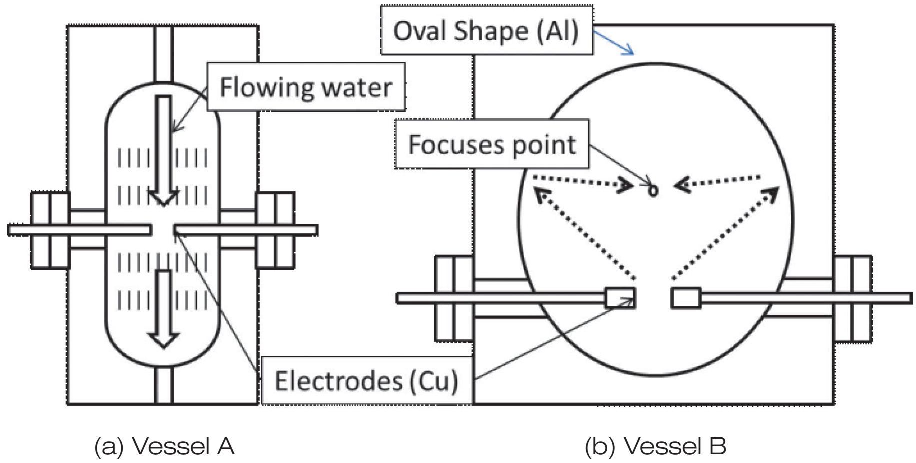


Figure 2. The pressure vessel for visualization

2.2 UNDERWATER SHOCK WAVE GENERATOR AND MEASUREMENT OF DISCHARGE CHARACTERISTICS

Fig.3 shows underwater shock wave generator and setup for measurement device. An input power supply of shock wave generator is used AC100V. The power supply has been step up to 3500V by the transformer. And, it has been rectified by diode (NEC, 2D600M). And, it is charged to capacitor (TOEI, 4500V, 200uF). An electrostatic energy (U) is calculated by Equation (1). When total electric capacity C=800uF and charging voltage V=3.5kV; the electrostatic energy U = 4.9kJ. When to turn on a gap switch by an air actuator; the shock wave is generated between electrodes into vessel at the same time with spark discharge. The voltage and current of discharge between electrodes are measured by an oscilloscope connected with a high voltage probe (Testec, TT-HVP15HF, 15kV, 50MHz) and a Rogowski coil (Pemuk, TYPE CWT 150B). Thereby, we consider the discharge characteristics for the underwater shock wave generator.

$$U = \frac{1}{2}CV^2 \tag{1}$$

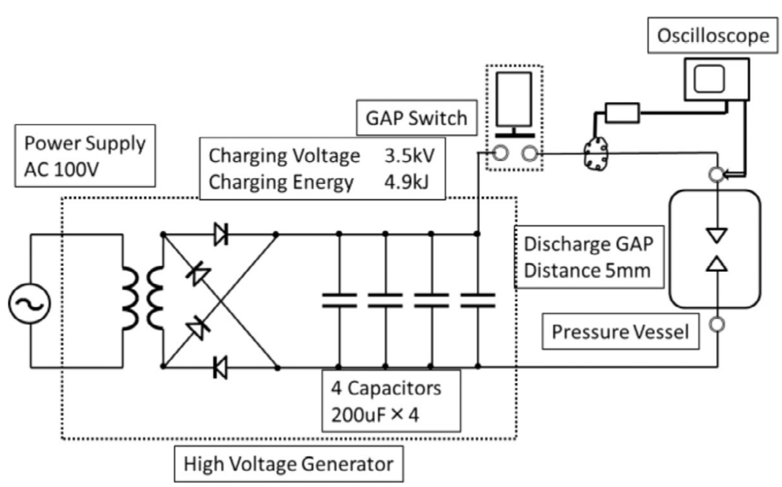


Figure 3. The experimental circuit and measurement of the electrical characteristics

2.3 THE OPTICAL OBSERVATION BY HIGH SPEED CAMERA

Two high speed cameras (Shimazu, HPV-1, 1Mfps and Nobby Tech, PhantomV7.3, 500kfps) were used to observe a shock wave and a discharge phenomenon. Fig.7 shows the setup of experimental apparatus for optical observation using shadowgraph method. A pressure vessel was set up to at the center of the pit. A xenon light was set at the behind the pressure vessel in the pit. Two high speed cameras and the shock wave generator were setup to outside of the pit. A trigger signal of the high speed camera was used by a current signal measured using a Rogowski coil. The later part of the discharge phenomenon was observed by to delay the trigger using delay generator. The photograph data of the high speed camera were stored in a computer.

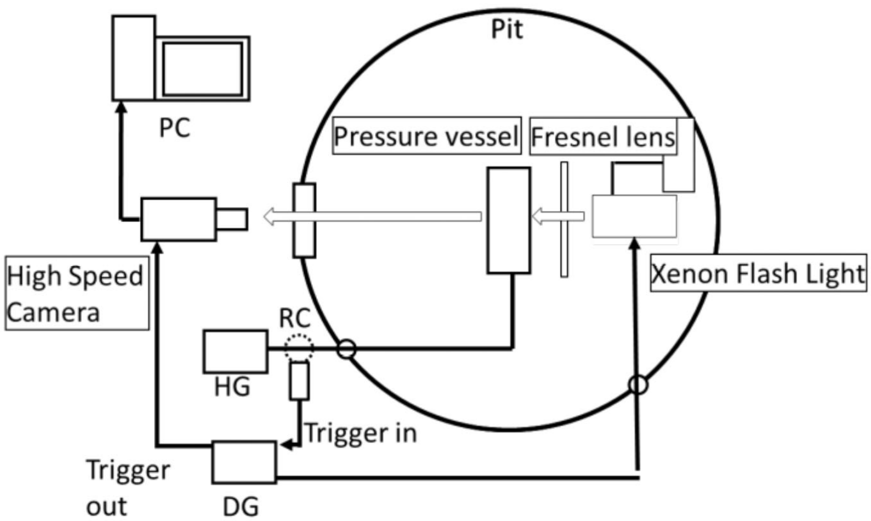
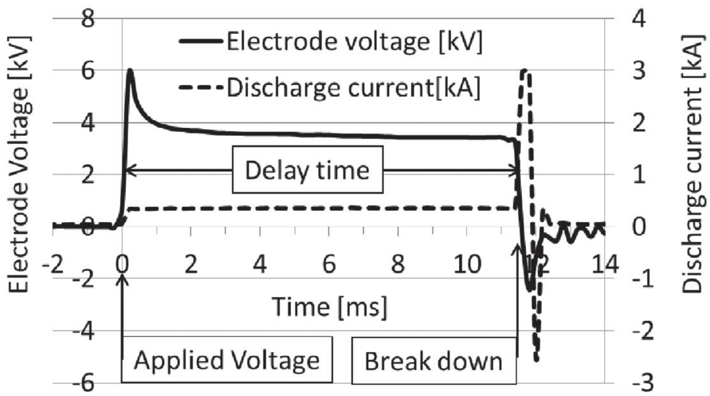


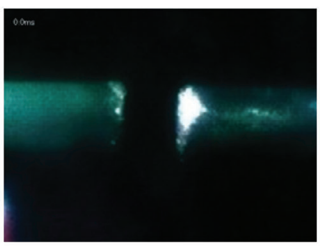
Figure 4. The set up device for optical measurement

3. EXPERIMENTAL RESULTS AND DISCUSSION

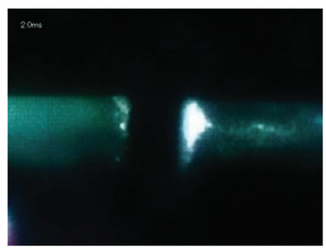
3.1 THE VOLTAGE CURRENT CHARACTERISTICS AND THE PHOTOGRAPH OF HIGH SPEED CAMERA FOR FROM APPLIED VOLTAGE TO ELECTRIC BREAKDOWN

Fig.6 shows the voltage current characteristics and the photograph of the high speed camera for from applied voltage to electric breakdown. The horizontal axis is the elapsed time since voltage is applied between two electrodes, the vertical axis is the voltage and the discharge current between two electrodes. The photograph is the state of between two electrodes at the elapsed time. In the photograph, the left electrode is anode; the right electrode is cathode. The vessel A was used in experiment; the distance of electrodes was 4mm; the diameter of electrode was 5mm; the charged voltage was 4kV. The delay time of 11.5ms has occurred for from applied voltage to electric breakdown. The voltage of between electrodes was 3.3kV at the time of 11.4ms just before breakdown. The state of electrodes was looked no change by the photograph at the just time of applied voltage (Fig.5 (a)). It was looked that the tiny bubble occurred in the tips of cathode electrode at the time of 2ms (Fig.5 (b)). At the time of 9ms (fig.5 (c)), the tiny bubble of cathode were extended to anode electrode, It was looked that the tiny bubble occurred in the tips of anode electrode. The bubble occurred in tips of

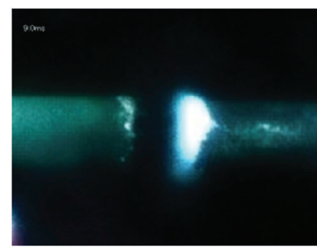




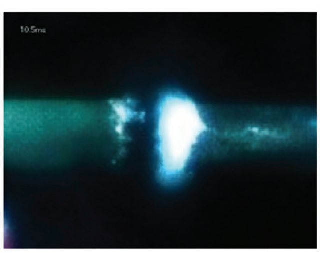
(a) 0ms



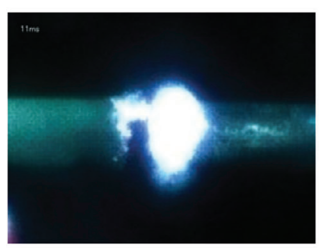
(a) 2.0ms



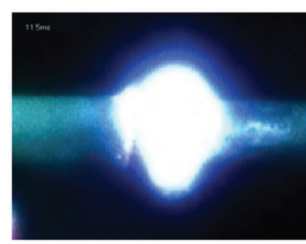
(a) 9.0ms



(a) 10.5ms



(a) 11.0ms



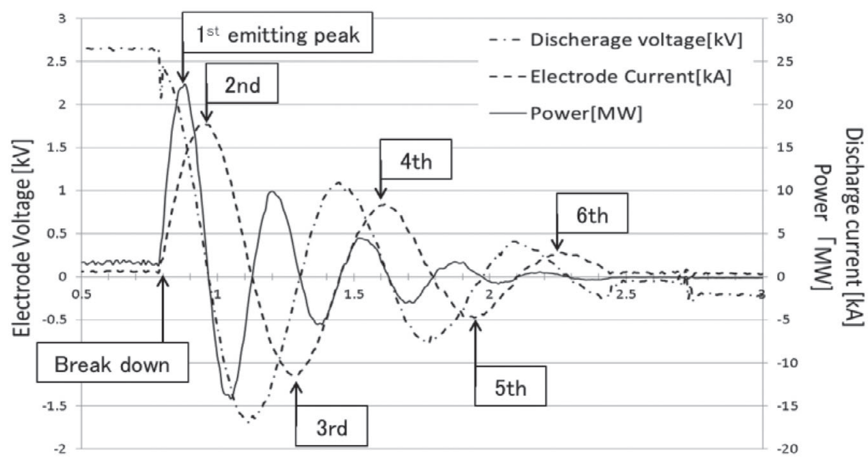
(a) 11.5ms

Figure 5: Voltage current characteristics and photograph of high speed camera after applied voltage

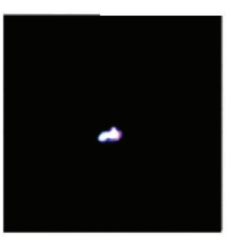
electrodes were more extended, them were connected each other at the time of 11ms. At the time of 11.5ms, the isolation of between electrodes was destroyed, the spark discharge was observed. In each case, it was observed that the electric breakdown was occurred after the bubble generated in tips of electrodes were connected each other; we consider that the cause of electric breakdown is generation and connection of the babble. Because the current has been continues to leak while the delay time, the electrostatic energy was decrease from 4.3kJ to 2.9kJ at the just before electric breakdown. We consider that the longer delay time was increased the energy loss.

3.2 THE DAMPED OSCILLATION OF ELECTRIC DISCHARGE AND THE LIGHT EMITTING PHENOMENON

? Fig.6 shows the voltage current characteristics and the photograph of the high speed camera after the electric breakdown. The horizontal axis is the time, the vertical axis is the voltage and the discharge current between two electrodes. The vessel B was used in experiment; the distance of electrodes was 5mm; the diameter of electrode was 20mm; the charged voltage was 3.5kV. The high speed camera Phantom V7.3 was used, the sampling rate was 88,888fps, and the expose time was 25.75us. The discharge characteristics of the capacitor discharge circuit is generally known that the 3 modes. These modes are the damped oscillation, the critical damping and the overdamping. These are changed by relation of resistance R, capacitance C and reactance L. Fig 7 shows these discharge characteristics[5]. The discharge characteristics of shock wave generator were showed damped oscillation.



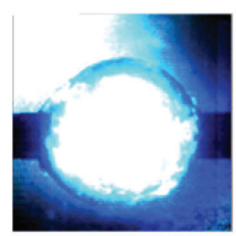
(a) Voltage Current characteristics after break down



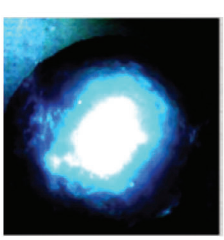
(b) Break down (0.78ms)

(c) 1st Peak (0.86ms)

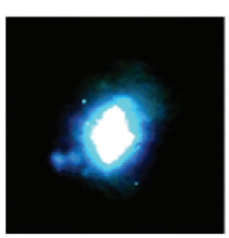
(d) 2nd Peak (0.9ms)



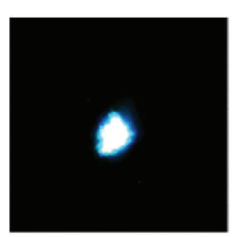
(e) 3rd Peak (1.29ms)



(f) 4th Peak (1.62ms)



(g) 5th Peak (1.95ms)



(h) 6th Peak (2.28ms)

Figure 6: Light emitting and damped oscillation of discharge

Furthermore, the gas expansion associated with light emitting was observed by the photograph of the high speed camera. These gas expansions have been synchronized with the discharge current. We are considering that a water of dielectrics and the capper of electrodes became the plasma by the discharge energy. After the second times plasma expansion, the plasma was generated into other gas generated by fist plasma expansion.

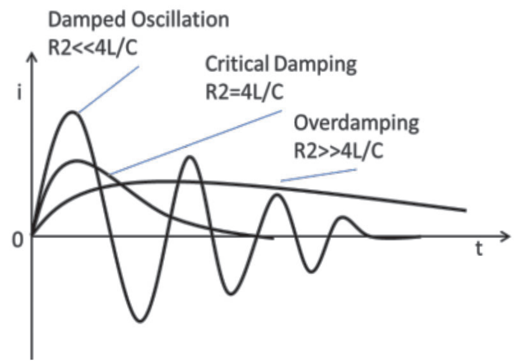


Figure 7: Three discharge mode of capacitor discharge circuit

3.3 THE OPTICAL OBSERVATION OF THE UNDERWATER SHOCK WAVE

Fig 8 shows the photograph of the underwater shock wave observed by shadowgraph method. Fig 8 is the photograph at the time of 50us after trigger. The radiated shadows around electrodes are shadows of the shock wave generated by the underwater discharge. The high speed camera HPV-1 was used, the sampling rate was 500,000fps, and the expose time was 1/8us. The countless shock waves were generated around electrodes after electric discharge. The countless shock waves were connected each other, these were became 3 clear waves. Table 1 shows the 3 waves velocity U and the pressure P calculated by Equation (2). The wave C is faster than the sonic Us (1450m/s) of underwater. The pressure P calculated by the velocity was 58MPa. The shock wave around electrodes had been generated during 80us after electric discharge. Fig 9 shows the time change of the discharge energy. The peak of discharge current was 17.7kA, the pulse wide was 336us, and the peak power was 18MW. The time observed the shock wave generation means the rise time of the discharge energy at the first times. The time of first plasma expansion showed Fig 6(a) was the time of the shock wave generation. The shock wave was not observed after second times plasma expansion. The shock wave is considered to have been attenuated by the gas generated with first times plasma expansion. We consider that the damping oscillations after the second times were not caused to the shock wave generation. The energy used by the underwater shock wave generation is about 30% of the all discharge energy, the other energy is considered to have been used by joule heat and pressure wave. It is considered to need that the most of energy is released to the first times peak of discharge. We consider that the discharge by critical oscillation is effective, it release the energy without oscillation at the short time.

$$\mathrm{P} = \rho_0 U_s \frac{u_s - u}{s} \tag{2}$$

P: Pressure of a shock wave [MPa], ρ_0: Density of a water (1000kg/m^3)
Us: Sonic in water (1450m/s), S=1.79

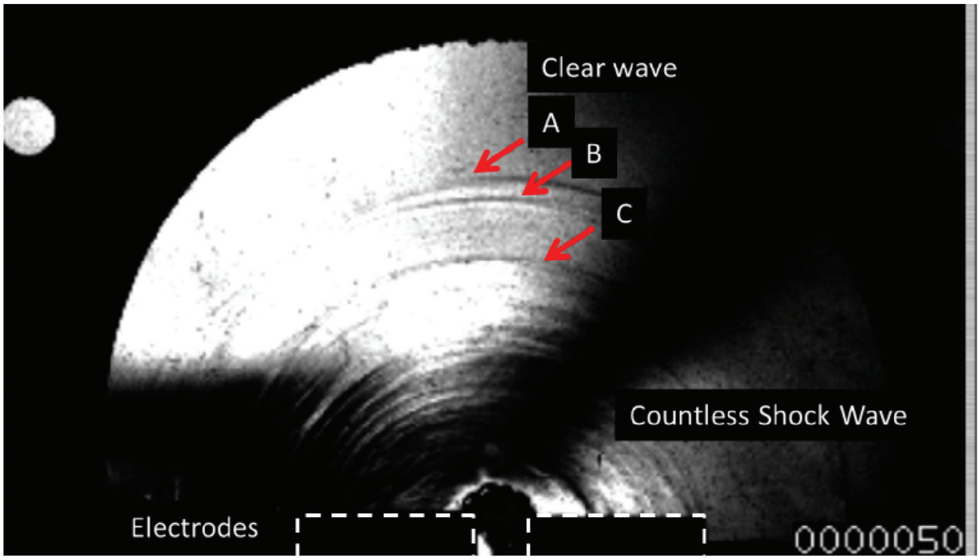


Figure 8. Photograph of shock wave at time of 50us after electric discharge

Table 1. Velocity and pressure of 3 clear waves

Waves	Velocity [m/s]	Pressure [MPa]
A	1439	Null
B	1396	Null
C	1518	58

4. CONCLUSIONS

In order to research a mechanism of the shock wave generation and the energy efficiency by the underwater discharge, we carried out the measurement of voltage and current characteristics at the underwater discharge and the optical observation using the high speed camera. As a result of research, the following contents became clear.

(1). The time delay is occurred during from the applying voltage to the electric breakdown. During delay times, the electric breakdown is occurred after that the gas bubbles generated between electrodes was connected. The cause of electric breakdown is gas bubbles in water. The charging energy and the voltage are decreased before the electric breakdown.

(2). The voltage current characteristics show the damped oscillation. The plasma expansion synchronized damped oscillation was observed between electrodes. The first times plasma expansion was generated in water. But, the plasma expansion after second times was generated in the gas bubble generated by first plasma expansion.

(3). The underwater shock wave is generated countlessly by first plasma expansion in water, it is not generated by plasma expansion after second times oscillation in gas bubble. Thereby, one part of energy was used to shock wave generation when the energy was released by damped oscillation. We consider that the discharge by critical oscillation is effective.

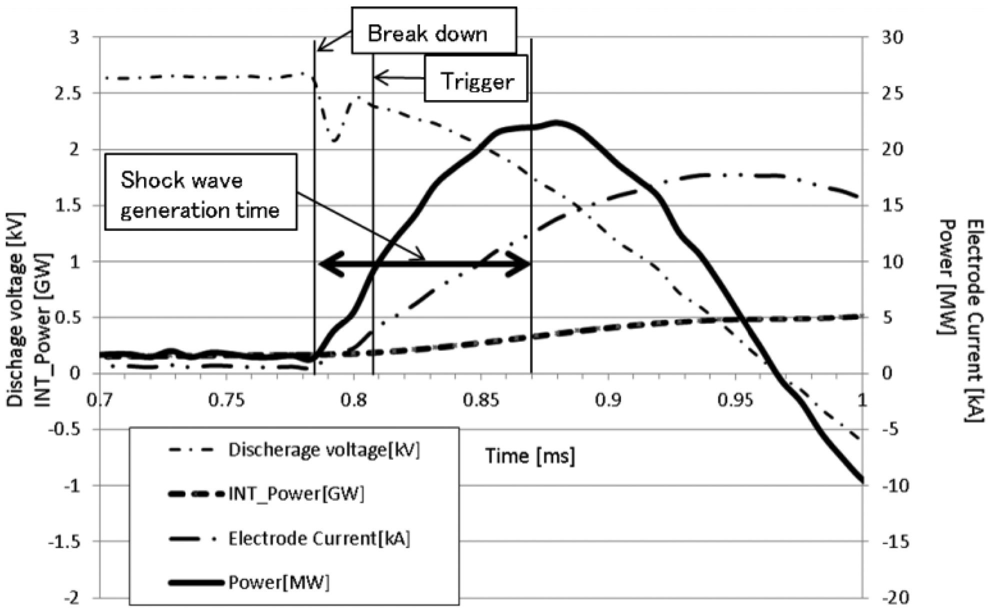


Figure 9. Relationships between discharge power and shock wave

REFERENCES

[1] FOOD ACTION NIPPON?http://syokuryo.jp/index.html

[2] T.Sakugawa, T.Yamaguchi, K.Yamamoto, J.Choi, T.Kiyan, T.Namihira, S.Katsuki, H.Akiyama: "Generation of Streamer Discharge Plasma in Water by All Solid-State Pulsed Power", *IEEJ Trans. FM*, Vol.126, No.7, pp.703-708 (2006)

[3] Y.Miyafuji, K.Shimojima, S.Tanaka, K.Naha, T.Aka, H.Maehara, S.Itoh: "Development of the Pressure Vessel for Manufacturing the Rice-Powderusing Underwater Shock Wave", *ASME2011*, PVP2011-58033 (2011)

[4] A.Oda, N.Okamoto, S.Itoh: "Study on the Relationship between Some Foods and Underwater Shock Wave Using the Explosion of the Detonation Fuse", *Materials Science Fouram*, Vol.566 pp.197-202 (2008)

[5] R.Hanaoka, "High Voltage Engineering"; Morikita Publishing Co.,Ltd. (2007)

[6] S.P.Marsh, "Lanl Shock Hugoniot Data", University of California Press Berkely, Los Angeles, London, pp.573 (1980)