

Numerical Analysis of the Behavior of Shock Wave in Spheroid Vessel

Yosuke Nishimura*, Naoki Kawaji, Shigeru Itoh*****

*Graduate School of Science and Technology, Kumamoto Univ., Japan

**Graduate School of Science and Technology, Kumamoto Univ., Japan

***Shock Wave and Condensed Matter Research Center, Kumamoto Univ., Japan

ABSTRACT

Food processing utilizing underwater shock wave softens the food by breaking cells, and prevents loss of nutrients since there is little influence of heat. Moreover, it is also possible to extract a nutrient easily and reduce processing time. A device to generate a high intensity shock wave is required in order to process various kinds of food. The purposes of this research are to investigate the best condition to generate high intensity shock waves and to understand the behavior of converged shock wave.

The capacitor electric discharge circuit was used as an underwater shock wave generating device. The waveform of discharge voltage and current were measured in order to search for the best condition of underwater discharge. It was confirmed that the larger charge voltage of capacitors become, the larger optimum electrodes interval become. Propagation and convergence of underwater shock wave was observed by numerical analysis.

Keywords: Shockwave, Underwater discharge, Convergent, Food processing

1. INTRODUCTION

Eating habits become rich because the food processing technology develops. The conventional food processing are boil and burn, steam and so on for the improvement of safety and preservation. These are processing by heating. However there is loss of nutrient as a problem.

We propose food processing using underwater shock wave. The features of this technology are following.

- Processing is momentary.
- Energy saving.
- Nutrition is kept because the influence of heat is not almost caught.
- Improvement of softening and extraction.

The conventional method of generation of underwater shock wave is to utilize the underwater detonation of the explosive. But the fault of this method is following.

- Redundancy of a cycle time.
- Pollution of water by remains of the explosive.
- Legal restrictions.

Therefore it proposes the utilization of the underwater shock wave generated by the electrical discharge of impulse large current.

The device to generate high intensity shock wave is required in order to process various kinds of food. The purposes are to investigate that optimum condition to generate high intensity shock wave and the behavior of converged shock wave.

2. METHOD OF EXPERIMENT

2.1. THE IMPULSE LARGE CURRENT EQUIPMENT

The capacitor electric discharge circuit was manufactured as underwater shock wave generating equipment. The circuit diagram is shown in Fig. 1. Four oil capacitors (Made of Nichicon Corp. Capacitance: 25 μF , Withstand voltage: 20 kV) were connected in parallel. After charging capacitors with 8–14 kV , underwater shock wave was generated by discharging between the electrodes installed underwater. Furthermore, the hemispheres of 20mm in the diameter (made of brass) were employed for the electrodes to obtain a semi-equal electric field. Generally a spark occurs without going by way of corona discharge in semi-equal electric field.⁽¹⁾

2.2. DISCHARGE VESSEL

2.2.1. Vessel for shock wave convergence

Fig. 2 was manufactured as vessel for shock wave convergence. The material is SUS, and the parts of isolation are polyacetal resin. The reflector plate is hemisphere of spheroid (Long radius = 103 [mm] , Short radius = 93 [mm]). Discharge part and pressure measurement point are respectively located in primary focus and secondary focus. Electrodes interval is “ d [mm] ”. At the time of experiment the inside of vessel is filled with water.

2.2.2. The metallic large container

At the time of experiment without pressure measurement the metallic large container was employed since spheroid vessel had low durability. Silicon rubber plate was bedded for isolation inside the container.

2.3. MEASUREMENT EXPERIMENT

“Charge voltage” and “Capacitance”, “Electrodes interval”, “Length of circuit cable” are considered as parameters to effect intensity of underwater shock wave. According to the former experiment (2) it was confirmed that optimum electrodes interval existed in every

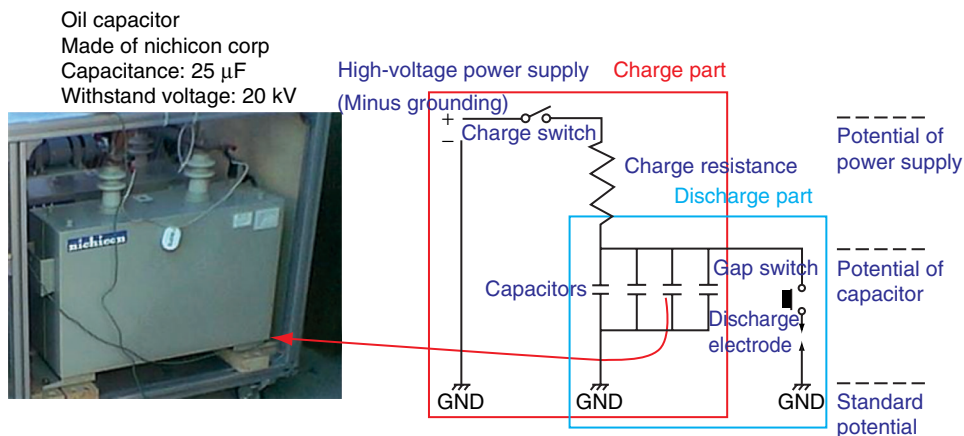


Figure 1 The circuit diagram of the impulse large current equipment.

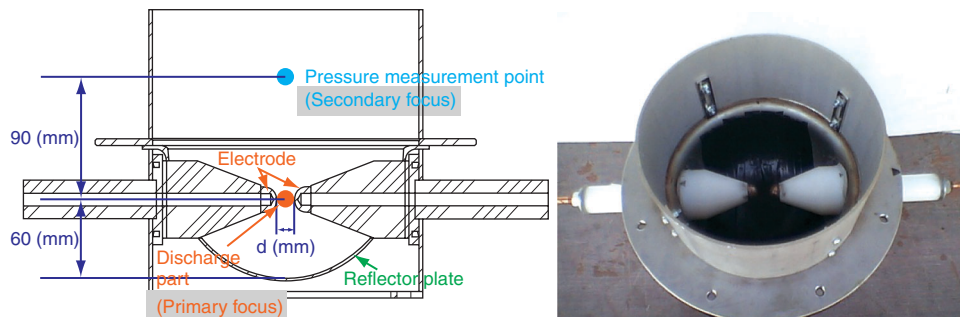


Figure 2 Schematic and photograph of vessel for shock wave convergence.

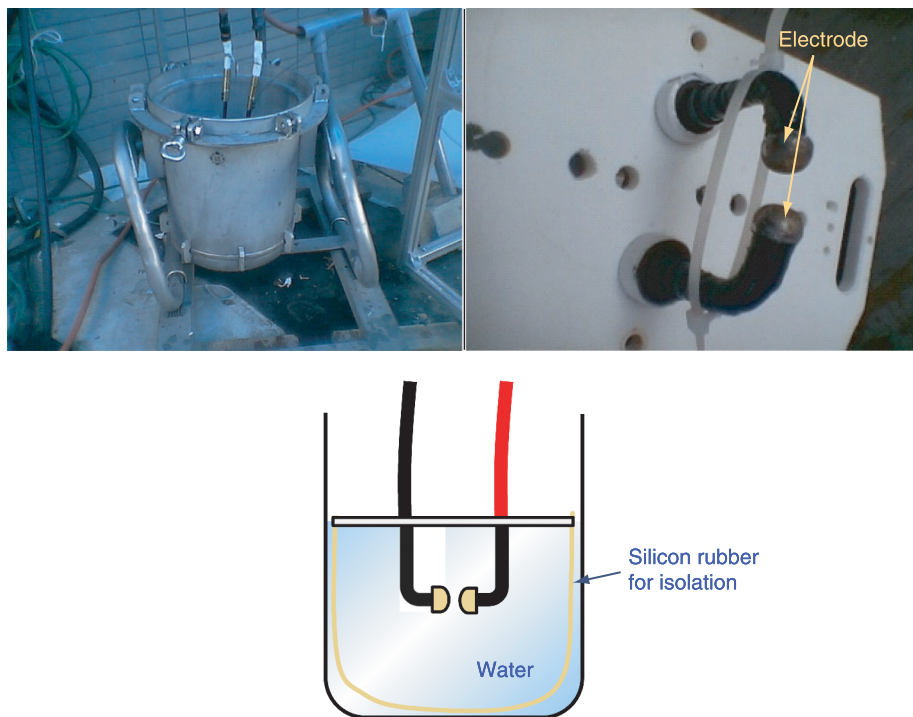


Figure 3 Photograph and schematic of the metallic large container.

combination of “Charge voltage” and “Capacitance”. In this research “Capacitance” was 100 [μF] and the purpose was to requested the optimum electrodes interval in each “Charge voltage”. The influence was investigated which “Length of circuit cable” had on the intensity of underwater shock wave. Maximum discharge power [W] is defined as barometer of intensity of shock wave, because measurement of pressure of shock wave was mistaken. Wave form was obtained by use of oscilloscope (Made of LeCroy).

2.3.1. Method of current measurement

Rogowski Current Transducer “CWT600” (Made of PEM [0.05 mV/A]) was employed. Fig. 4 shows condition of installation. The Rogowski coil was set up on high voltage cable between switch and electrodes.

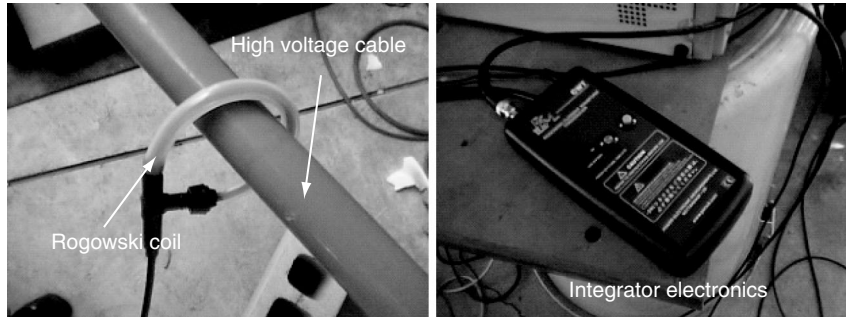


Figure 4 Condition of installation of Rogowski Current Transducer.

2.3.2. Method of voltage measurement

High Voltage Probe “PPE 20 kV” (Made of LeCroy [1/1000]) was employed. Fig. 5 shows condition of installation. The probe was connected to the terminal of capacitor.

2.4. NUMERICAL ANALYSIS BY LS-DYNA

Numerical analysis of shock wave convergence phenomenon was run. Fig. 6 shows Numerical analysis model. The size of this model was same as Fig. 2. It was 2D model and the electrodes and its supporter were omitted for simplification. Since it is difficult to simulate discharge phenomenon, SEP (High explosive made by kayaku-Japan) was installed in primary focus. The purpose of this simulation is to recognize propagation and convergence of shock wave. Fig. 7 shows flow of numerical analysis. At first geometry data was created by use of SolidWorks (3D-CAD software produced by SolidWorks Japan). This geometry data was imported in HyperMesh (CAE software produced by Altair) and meshed. This FE data was imported in LS-DYNA 3D (CAE software produced by LSTC) and defined analysis condition. Fig. 8 shows Numerical analysis condition.

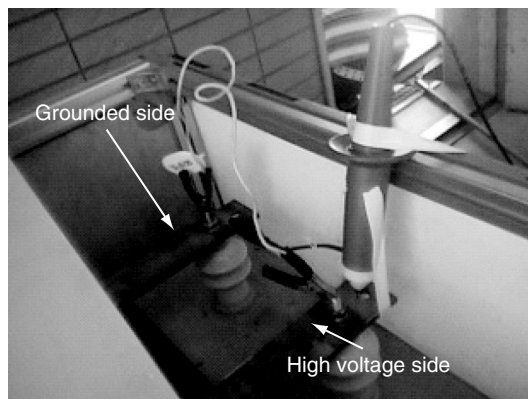


Figure 5 Condition of installation of High Voltage Probe.

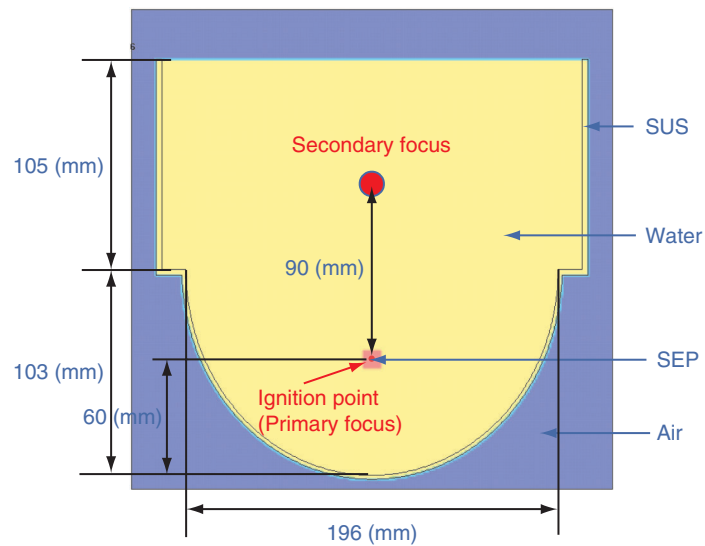


Figure 6 Numerical analysis model.

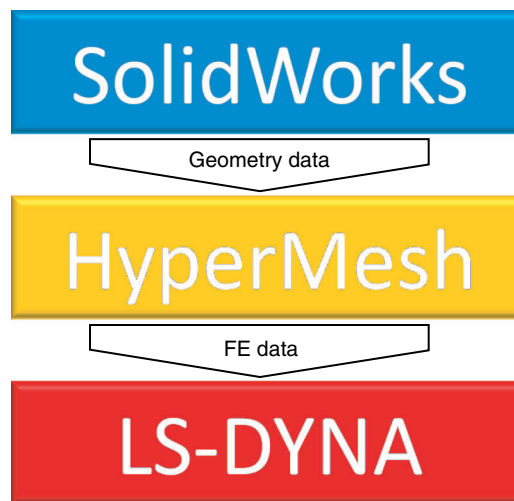


Figure 7 Flow of numerical analysis.

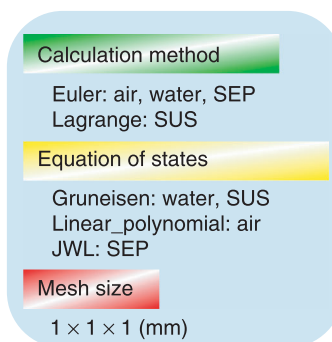


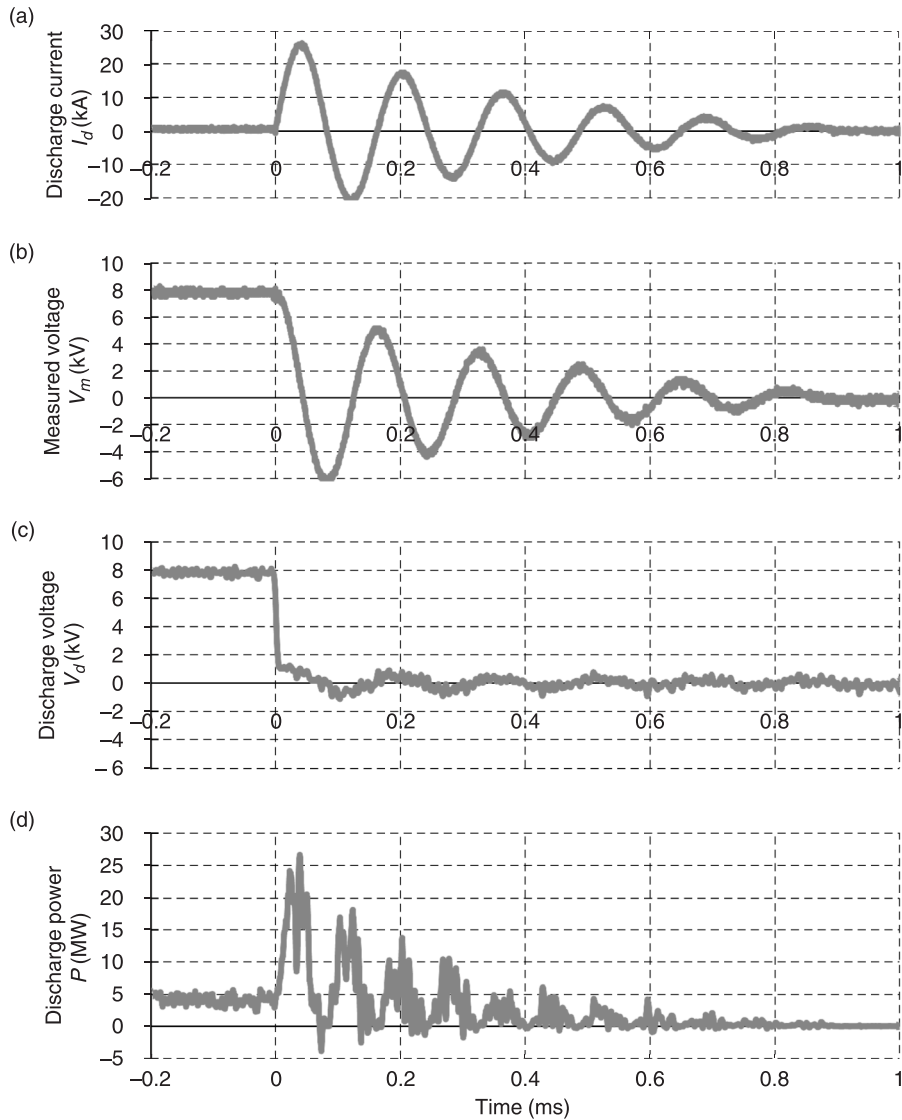
Figure 8 Numerical analysis condition.

3. EXPERIMENTAL RESULT & CONSIDERATION

3.1. MEASUREMENT RESULT

3.1.1. Property of typical underwater discharge

Fig. 9 shows property of typical underwater discharge and experimental condition. When high voltage was impressed between electrodes, the current of about 600 [A] flowed through water. It took 5~20 [ms] from impression of high voltage to initiation of discharge, and charge voltage decreased gradually in the meantime. The charge voltage before switching V_0 was 10 [kV], but the voltage of discharge initiation was 7.8 [kV]. Air bubbles are generated by



Charge voltage V_0 (kV)	Capacitance (μF)	Electrode interval d (mm)	Cable length (m)
10	100	10	3×2

Figure 9 Property of typical underwater discharge and experimental condition.

current and it resulted in arc electric discharge by discharge in air bubble. At the time of arc electric discharge the damped oscillation current flowed as Fig. 9 (a) and measured voltage V_m was also damped oscillation which phases differed 90 degrees from discharge current I_d . It was effect of inductance $L = 6.63$ [μH] included in measured circuit. Schematic of measured circuit and formula was shown in Fig. 10.

3.1.2. Optimum electrodes interval

Fig. 11 shows the relationship between electrodes interval d and maximum discharge current I_{\max} . Fig. 12 shows the relationship between d and maximum discharge power P_{\max} . Length of circuit cable was 3×2 [m]. The larger d became, the smaller I_{\max} became from Fig. 11. The

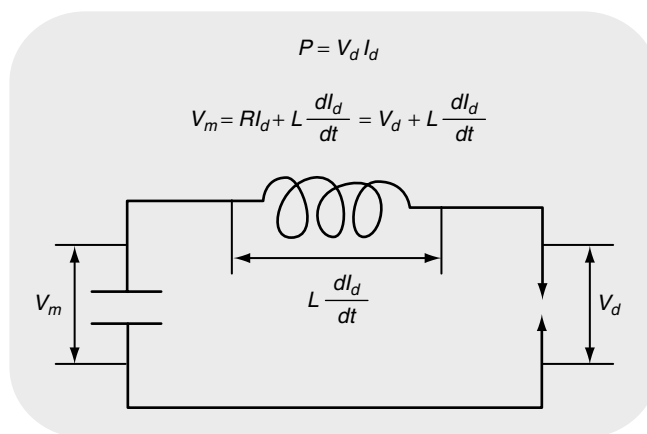


Figure 10 Schematic of measured circuit and formula.

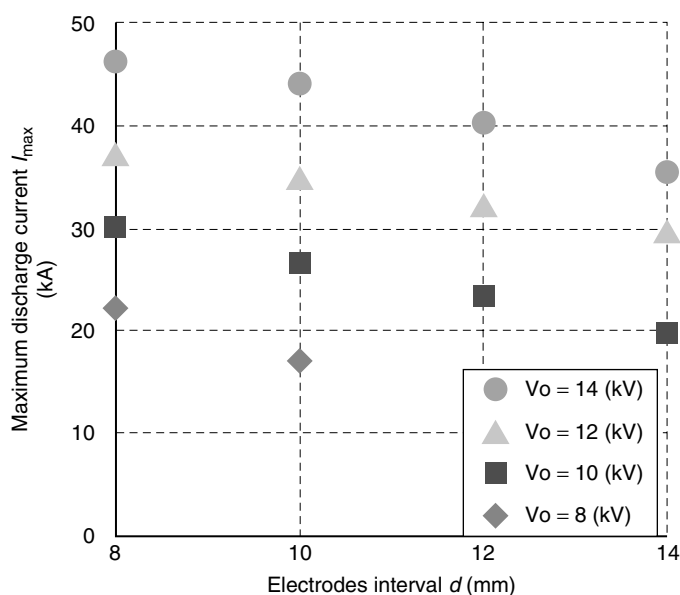


Figure 11 The relationship between electrodes interval and maximum discharge current.

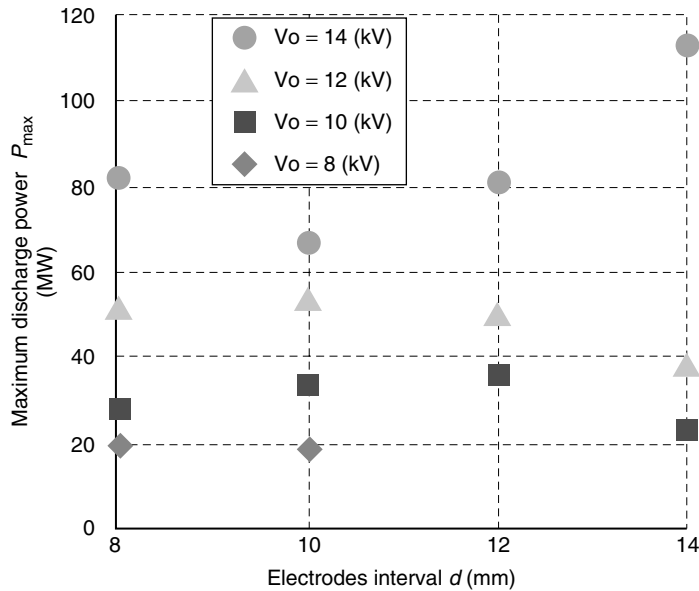


Figure 12 The relationship between electrodes interval and maximum discharge power.

cause is the following. When d become large the impedance of between electrodes increases and the voltage of discharge initiation decreases. In each charge voltage V_0 there were d that P_{max} became the largest from Fig. 12. The cause is the following. When d become large I_{max} decreases, but discharge voltage V_d increase because the impedance of between electrodes increases. As a conclusion it was confirmed that the larger V_0 became, the larger optimum electrodes interval became.

3.1.3. Length of circuit cable

Fig. 13 shows the relationship between length of circuit cable and P_{max} and experimental condition. When cable length was short, P_{max} was large from Fig. 13. The cause is the following. When cable length become long, inductance L increase, and intersection point of I_d & V_d becomes low, because I_{max} decreases and rising time of current become long. (3) Fig. 14 shows schematic of intersection point of discharge current and discharge voltage

3.1.4. Exceptional discharge phenomenon

Fig. 15 shows typical waveform of current. Fig. 16 shows property of typical waveform of current. Almost discharge was this mode.

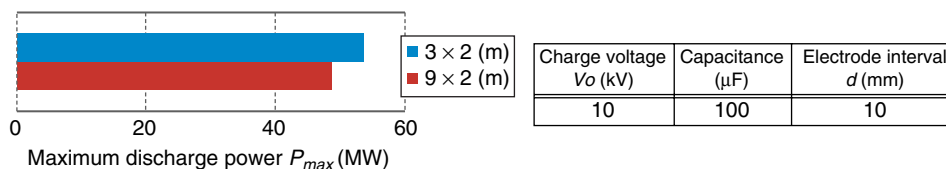


Figure 13 The relationship between length of circuit cable and maximum discharge power and experimental condition.

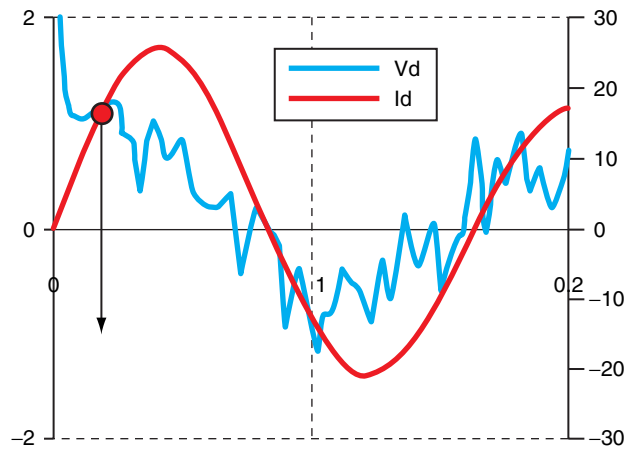


Figure 14 Intersection point of discharge current and discharge voltage.

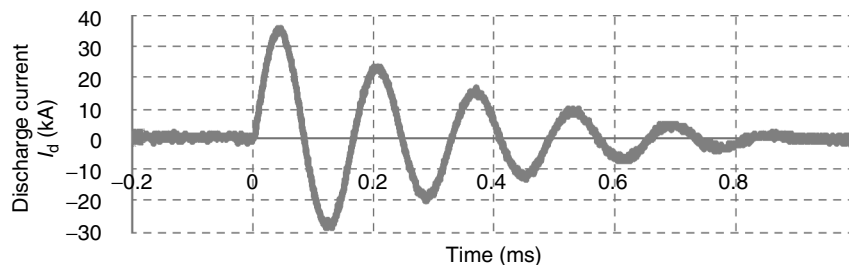


Figure 15 Typical waveform of current.

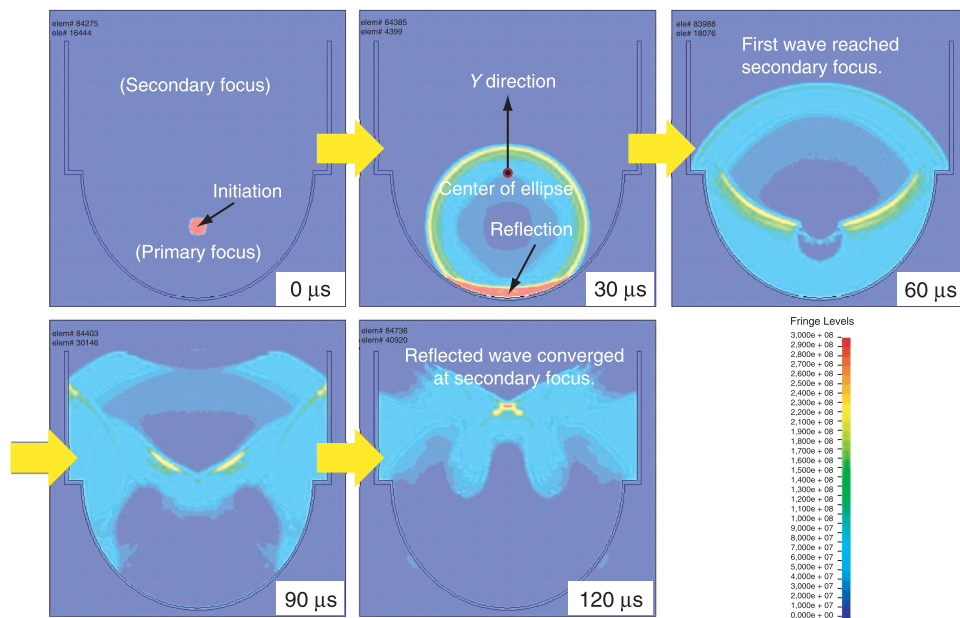


Figure 15a Propagation and convergence of underwater shock wave.

Mode of waveform	Damped oscillation
Occurrence condition	$R^2 < 4L/C$
Maximum discharge power P_{max} (MW)	59.8

Figure 16 Property of typical waveform of current.

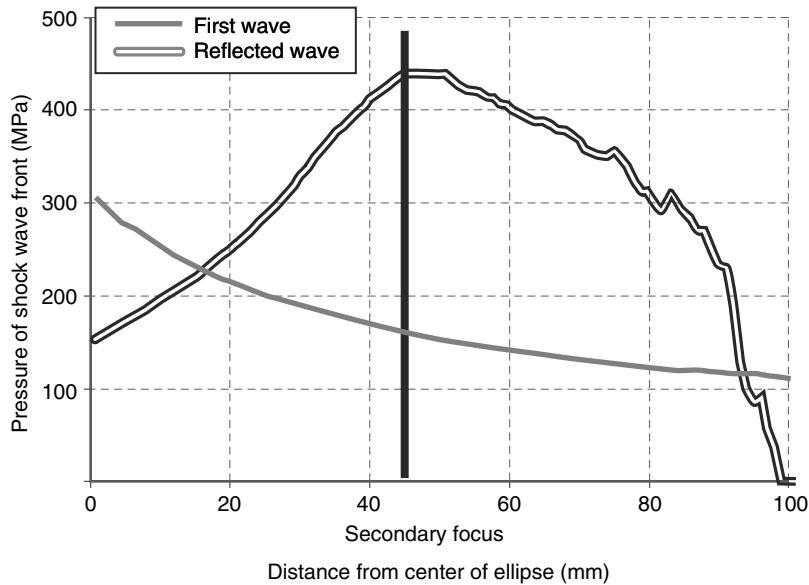


Figure 16a The relationship between distance and pressure of shock wave.

Fig. 17 shows exceptional waveform of current. Fig. 18 shows property of exceptional waveform of current. This mode occurred unusually. When electrodes interval was large, it was easy to happen.

Fig. 19 shows condition of two waveforms. These waveforms were same condition.

It is seemed that the shift of mode happen when impedance R become large from any causes, and P_{max} become large because energy is thrown in load efficiently in mode of critical damping. (4)

3.2. RESULT OF NUMERICAL ANALYSIS

Fig. 15 shows propagation and convergence of underwater shock wave. Secondary wave which reflected and converged by the reflector plate reached the secondary focus after first wave which generated in the primary focus reached the secondary focus from Fig. 15.

Fig. 16 shows the pressure variation of first wave and reflected wave above Y direction from center of ellipse. Pressure of reflected wave became maximum near secondary focus ($Y = 45$ [mm]) from Fig. 16. Fig. 17 shows the time history of pressure at secondary focus. The pressure of reflected wave was about 2.7 times larger than the pressure of first wave at secondary focus from Fig. 17.

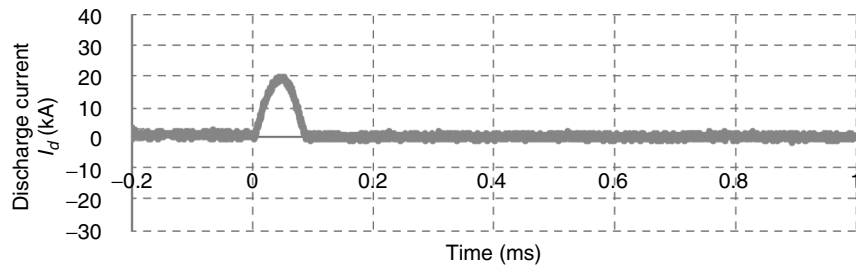


Figure 17 Exceptional waveform of current.

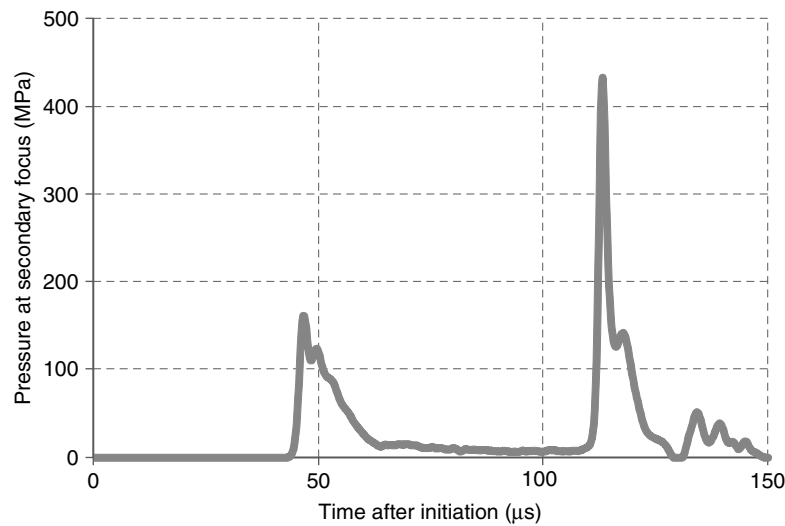


Figure 17a The relationship between time and pressure of shock wave.

Mode of waveform	Critical damping
Occurrence condition	$R^2=4L/C$
Maximum discharge power P_{max} (MW)	121.3

Figure 18 Property of exceptional waveform of current.

Charge voltage V_0 (kV)	Capacitance (μ F)	Electrode interval d (mm)	Cable length (m)
14	100	14	3×2

Figure 19 Condition of two waveforms.

4. CONCLUSION

In this research the purposes were to investigate that optimum condition to generate high intensity shock wave and the behavior of converged shock wave. The results of present stage are shown below.

- Property of typical underwater discharge was confirmed.
- The larger electrodes interval d became, the smaller maximum discharge current I_{max} became.
- The larger charge voltage V_0 became, the larger optimum electrodes interval became.
- When cable length was short, maximum discharge power P_{max} was large.
- The shift of waveform happened when impedance R became large from any causes, and maximum discharge power P_{max} became large.
- In the vessel for shock wave convergence pressure of reflected wave was about 2.7 times larger than the pressure of first wave at secondary focus.

REFERENCES

- [1] Masanori Akasaki (2005), "Basic high voltage engineering", Japan, (pp. 66–67)
- [2] Yusuke Sasaki (2009), "Research on the optical observation and pressure measurement of underwater shock wave by electric discharge", Undergraduate, Kumamoto university
- [3] Yuya Hayashida (2005), "Generation of shock wave by underwater spark discharge", Undergraduate, Kumamoto university
- [4] Hidenori Akiyama (2003), "High voltage pulse power engineering", Japan, (pp. 94)