國立成功大學

太空與電漿科學研究所

年度報告

National Cheng Kung University
Institute of Space and Plasma Sciences

Annual report

研究生: 劉嘉楷 Jia-Kai Liu

指導教授: 張博宇 Po-Yu Chang

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Contents

1. Abstract

Extreme ultraviolet(EUV) lithography is considered to be one of the most advanced technologies in this generation of semiconductor manufacturing processes. We would like to generate the EUV lithography light sources by using discharge produced plasma (DPP). We built a pulsed-power system to compress the plasma plume generated by a plasma gun. A current monitor is needed to measure the largest current from the pulsed-power system. Thus, the Rogowski coil is one of the necessary equipment for our pulsed-power system because the general ammeter can't handle the extremely large current from the system. Building and calibrating the Rogowski coil which is used to measure the large current are our first goal. We would like to fix it in the vacuum chamber of our pulsed-power system. We measure the discharged current of our pulsed-power system via the induced voltage of the Rogowski coil. As mentioned above, we are focusing on the plasma gun. A plasma gun is built by a pulsed-valve system, a reservoir system and a discharged system The second goal in this report is to build the pulsed-valve system. We introduce the structure of the pulse valve and the application we are going to accomplish. We also compare the performance of the 28-V pulse valve with the 12-V one. The circuit of the pulse generator was built and tested under different opening time.

2. Rogowski coil

Most of our experiments use the big current ~135 kA passing through the vacuum chamber. If we want to measure the value of current, we can't use the conventional ammeter to do it. The huge current will cause the conventional ammeter toasted. Therefore, we would like to use a Rogowski coil. Figure 1 shows the structure of the Rogowski coil. When a current passes through the coil, a voltage at the output of the Rogowski coil is induced. We measured the induced voltage with an integrator and then we could calculate the amount of the input current.

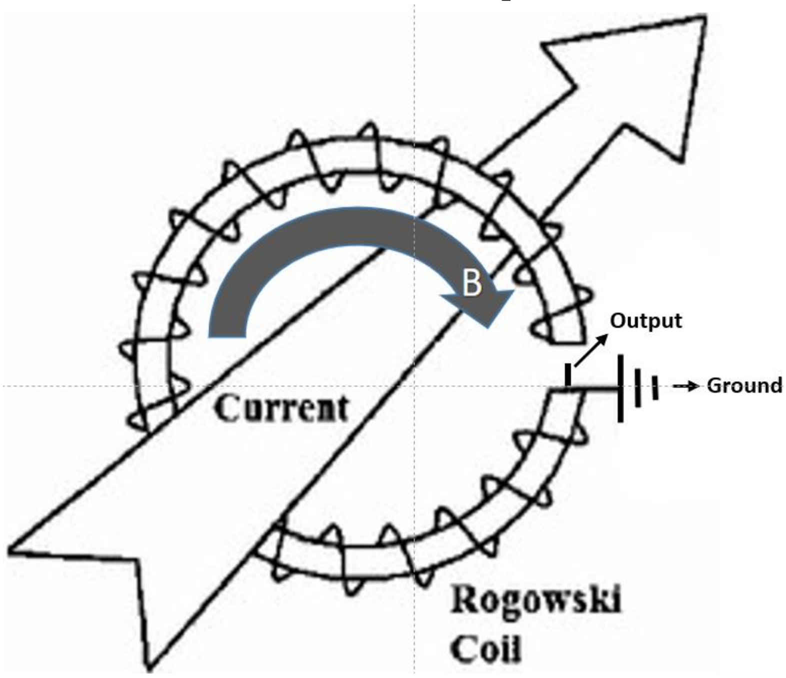


Figure 1: The principle of the Rogowski coil working.[1]

2.1 The design of the Rogowski coil

We placed the Rogowski coil in the vacuum chamber of our pulsed-power system locating between two cylinders of the cylindrical coaxial transmission line (CTL) shown as the green points in Figure 2. In figure 1, we connected the output side and the ground side with the BNC cable. The

Rogowski coil was fixed under the top plate of the CTL as shown in Figure 3. To fix the Rogowski coil at the location, we proposed two ways:

1. Use four Rogowski coil holders to hold the Rogowski coil under the top plate of the CTL. Figure 4 is the holder made of Polyethylene(PE). First, the Rogowski coil passes through four holders. Then, each holder is fixed under the top plate of the CTL using M2 screws.
2. Use four cable ties to hold the Rogowski coil under the top plate of the CTL. Figure 5 is the cable ties made of Polyethylene(PE). We simply made several holes through the top plate of the CTL and used cable ties to tie the Rogowski coil under the top plate of the CTL.

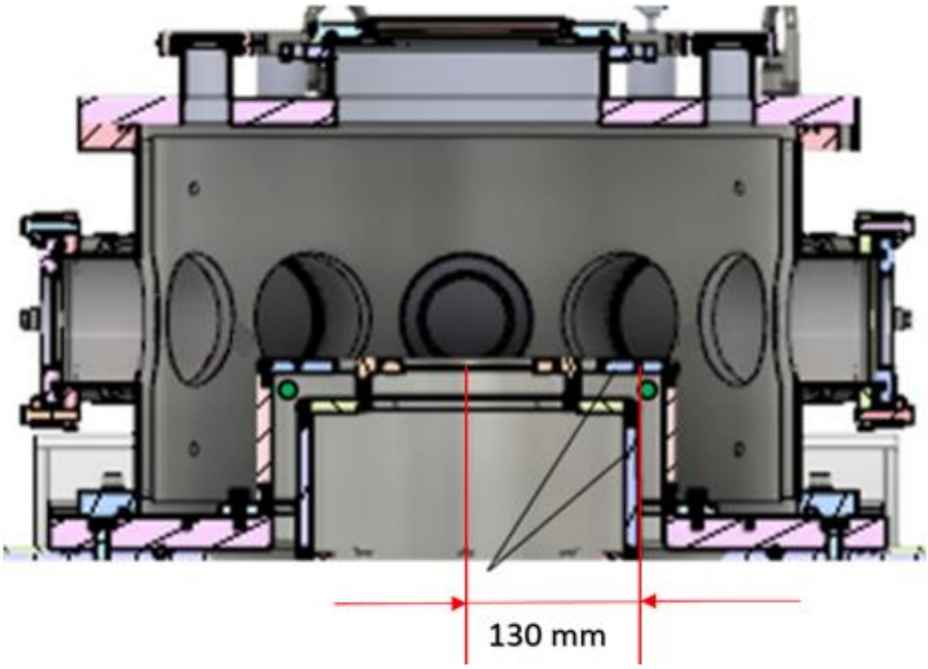


Figure 2: The sectional drawing of the vacuum chamber.

The size of the CTL limits the size of the Rogowski coil. It can be seen from Figure 2, which is the sectional drawing of the vacuum chamber and the CTL.

Figure 3: The sectional drawing of the coaxial outer and Rogowski coil.

Figure 4: Rogowski coil PE holder.

Figure 5: Cable ties.

To determine which way to use, we compared the workability, stability, and cost between two designs and showed it in Table 1 which is the comparison of advantages and disadvantages between the first version and the second version. The cable tie has a lower cost and easier workability than the PE holder. Therefore, we used the cable ties.

Table 1: The comparison of the Rogowski coil fixing methods.

	PE Holder	Cable tie
Workability	Difficult	Easy
Stability	Good	Bad
Cost	High	Low

2.2 The calibration of the Rogowski coil

The 1-kJ pulsed-power system is shown in Figure 6. After the Rogowski coil was fixed in the pulsed-power system, we need to calibrate the Rogowski coil in situ. As shown in Figure 7, we used four wires as the dummy load passing through the Pearson current monitor (model 301x) and connected between the anode (the outer cylinder of the CTL) and the cathode (the inner cylinder of the CTL). A PE plate was placed between the Pearson current monitor and the top plate of the CTL as the insulator.The 1-kJ pulsed-power system can provide a peak current of 135 kA. However, the maximum peak current that can be measured by the Pearson current monitor was 50 kA. Therefore, we disconnected the south wing of the pulsed-power system to reduce the current by half, i.e. ~50 kA. We measured the outputs of both the Pearson current monitor and the Rogowski coil when the pulsed-current passed through them at the same time. Then, we calculated the ratio between the current measured by the Pearson current monitor and the induced voltage of the Rogowski coil for calibration.

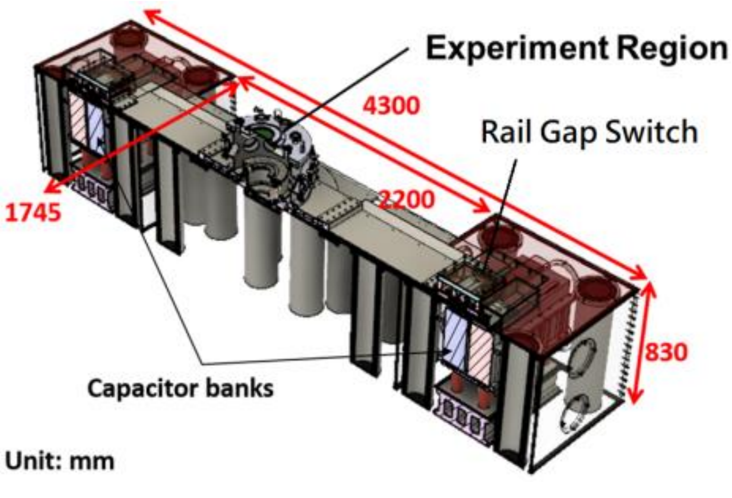


Figure 6: The drawing of the 1-kJ pulse power system.

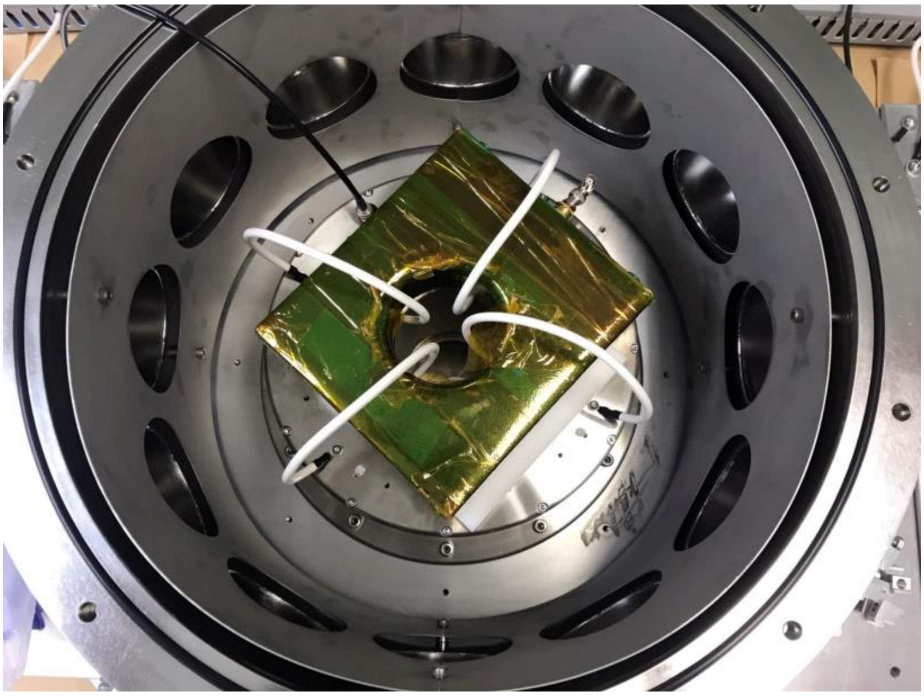


Figure 7: The Rogowski coil was calibrated with the Pearson current monitor.

2.3 Calibration result

Shown in Figure 8 is the result of the Rogowski coil curve fitting. The red dash line was the current measured by the Pearson current monitor while the blue solid line was the induced voltage of the Rogowski coil. To calibrate, we used Eq. (1) to fit the data shown in Figure 8 where I_{input}, α, w were fitting parameters.

$$I_{input}(t) = I_0 e^{-\alpha(t-\Delta t)} \sin(wt - \Delta t). \quad (1)$$

After curve fittings, we got the parameters I_{input}, t, w, α for both the Pearson current monitor and the Rogowski coil. We then plot the relation between the $V_{measured}(t)$ in x axis and $I_{input}(t)$ in y axis as shown in Figure 9. Then, we got the slope of Figure 9 which is the calibration ratio. As a result, the calibration ratio was 188000±296 (A / V).

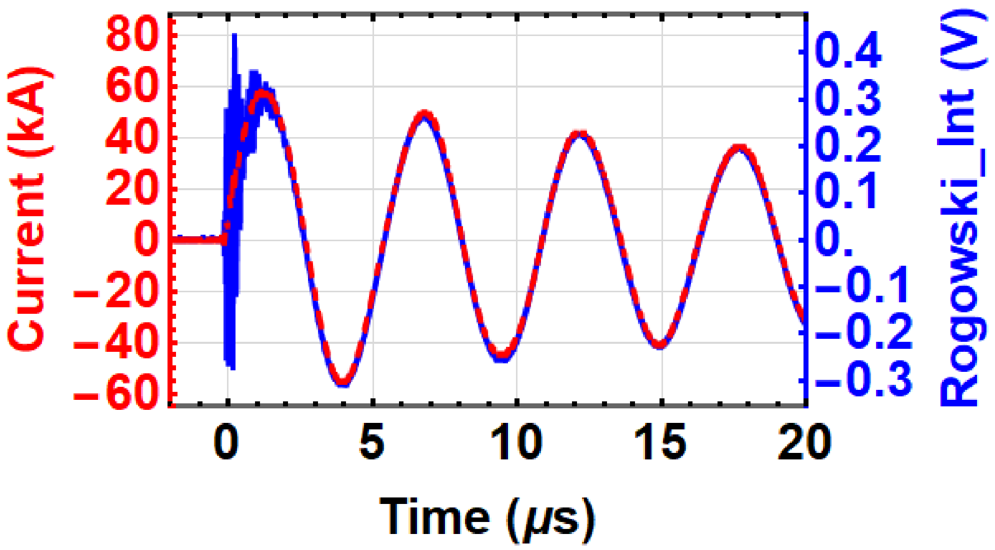


Figure 8: The result of the Rogowski coil curve fitting.

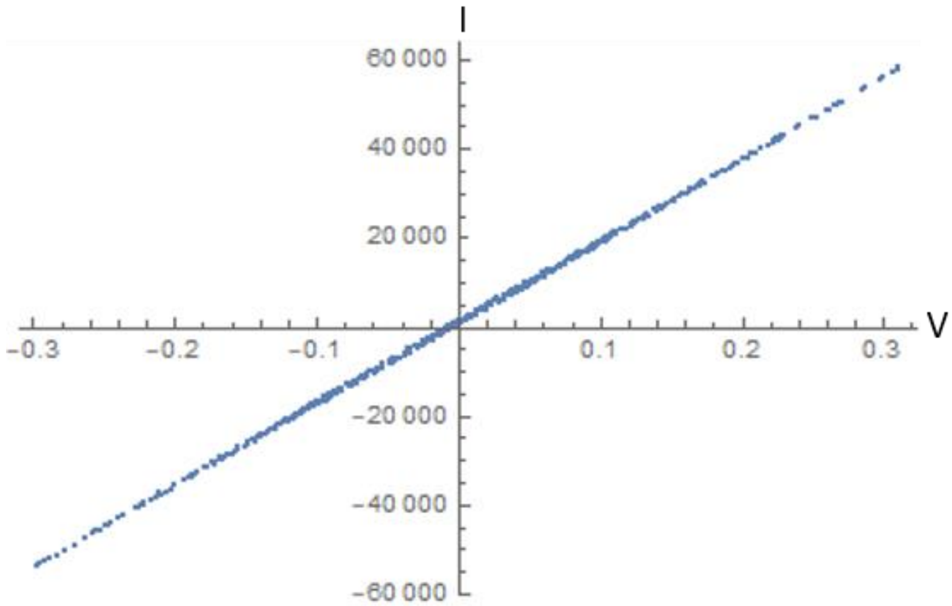


Figure 9: The relationship between input current and output voltage.

2.4 Current measurement of the pulsed-power system

After getting the calibration ratio, the measured current I_{input} can be obtained by Eq. (2).

$$I_{\text{measured}} = V_{\text{measurement}} \times \text{Calibration ration} \tag{2}$$

Then, we can use the Rogowski coil to measure the current provided by the full 1-kJ pulsed-power system. First, we removed the Pearson current monitor and kept the dummy load as shown in Figure 10. Figure 11 shows the measurement obtained from ten shots. The peak current was 135±1 kA.

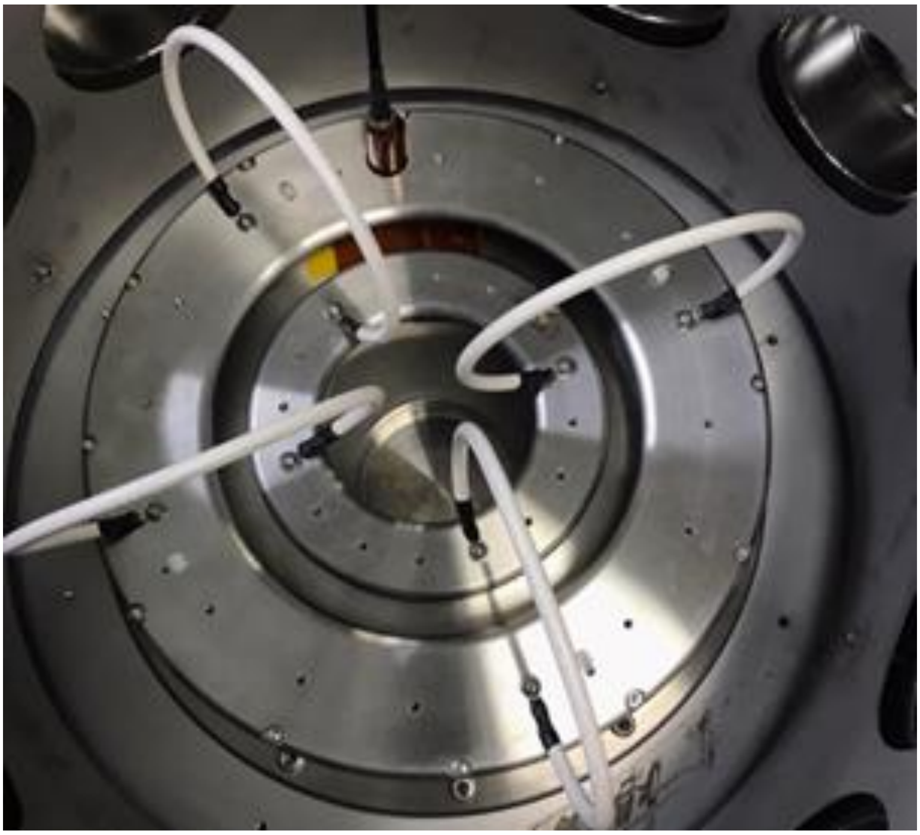


Figure 10: The Rogowski coil measured the current from the 1-kJ pulse power system.

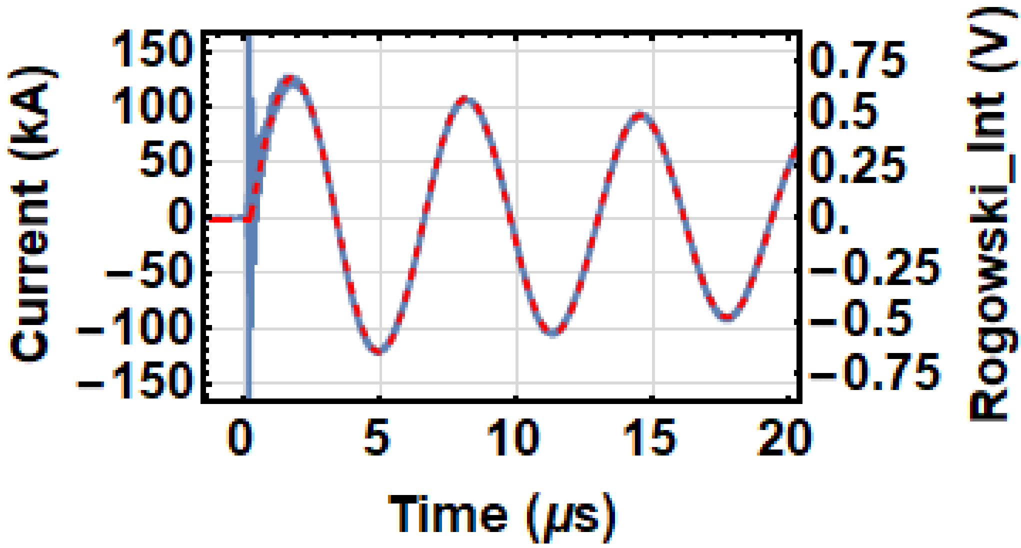


Figure 11: The current measurement from both of south and north wings triggered.

3. Pulsed-valve system

In my thesis work, I am focusing on generating plasma plume and measuring the propagating speed of the plasma plume. The plasma plume will be generated by a plasma gun that we are building. The plasma gun consists of a gas-puff system and the discharge electrodes, as shown in Figure 12. Before building the plasma gun, we need to build the gas-puff system consists of a pulse valve system.

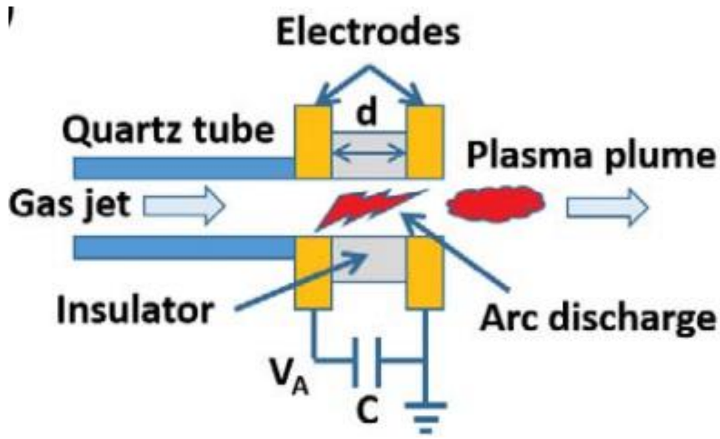


Figure 12: The pulse valve system was combined with the electrodes.[2]

3.1 The structure of the pulse valve

Figure 13 is the gas-puff system including a 28-V pulse valve, a signal control box and a reservoir. In this section, we are focusing on the pulse valve and the signal control box. The pulse valve was made by Parker Hannifin Ltd. As shown in figure 14, the bottom of the pulse valve is the gas exhaust port (port 1) and the top is the gas intake port (port 2). The pulse valve is a normally-closed valve and is opened only when a 28-V signal is applied to the pulse valve.

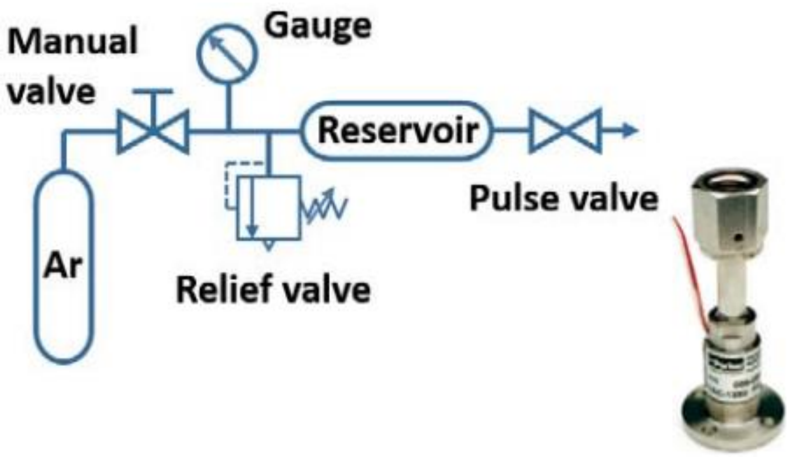


Figure 13: The pulse valve system with the reservoir and Argon source. [2]

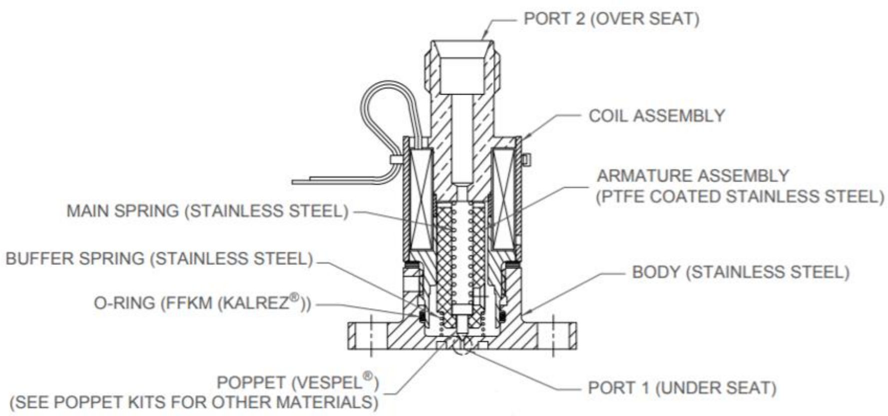


Figure 14: The structure of the 28-V pulse valve. [3]

3.2 The differences between 28 V and 12 V pulse valve

Because of the cost, we found the other pulse valve worked on 12 V, called 12-V pulse, as shown in Figure 15. The 12-V pulse valve is 20 times cheaper than the 28-V one. The 12-V one is also a normally-closed valve. The vacuum chamber of our 1-kJ pulsed-power system can be pumped down to 10^{-6} torr. Therefore, the pressure difference across the gas intake port and the gas exhaust port that the valve can handle is important. We made a comparison between the 28-V pulse valve and the 12-V one in Table 2. Table 2 shows the comparison of the working voltage and the working current between the 28-V and 12-V pulse valves. Table 3 shows the comparison of the pressure differences that can be handled between the 28-V and 12-V pulse valves. However, the pressure difference of the 28-V pulse valve is 64655 torr and the 12-V pulse valve is 562.5 torr. The requirements of my experiment is 760 to 2280 torr. Therefore, the 28-V pulse valve is suitable for my experiment.

Figure 15: The 12-V pulse valve.

Table 2: The comparison of the working voltage and working current.

	28-V Pulse valve	12-V Pulse valve
Working voltage	14 V	5.5 V
Working current	0.2 A	0.1 A
Power	2.8 W	0.55 W

Table 3: The comparison of the working pressure between the 28-V and 12-V pulse valve.

	12V DC Pulse valve	28V DC Pulse valve	In my experiment
Pressure difference	562.5 torr	64655 torr	(Experimental pressure - Chamber pressure) 760~2280 torr

3.3 The circuit of the pulse generator

The opening time of the 28-V pulse valve is really important. It can affect the pressure of the outputting gas since the pressure in the reservoir reduces as the gas is leaving the reservoir. In the purpose of controlling the opening time of the pulse valve, we use a relay (FOD3184) as the signal controller. In FOD3184, there is a LED in the input side combines with a voltage of output side. When the signal is generated from the function generator, the LED in the output side of the relay is activated. The voltage of output side of the relay V_{01} and V_{02} will be connected to the power supply, i.e. at 24V in our design. We used only 24V to trigger our pulse valve so that we don't damage the pulse valve by over voltage. As shown in Figure 16, to keep the input voltage stable, we use a DC-DC Converter and a 24-V battery to replace the power supply. Then, the fiber-optical-transmitter (FOT) is used to protect the function generator from the floating voltage in our 1-kJ pulsed-power system in the future. The fiber-optical-transmitter is stably powered by 5-V with a zena diode.

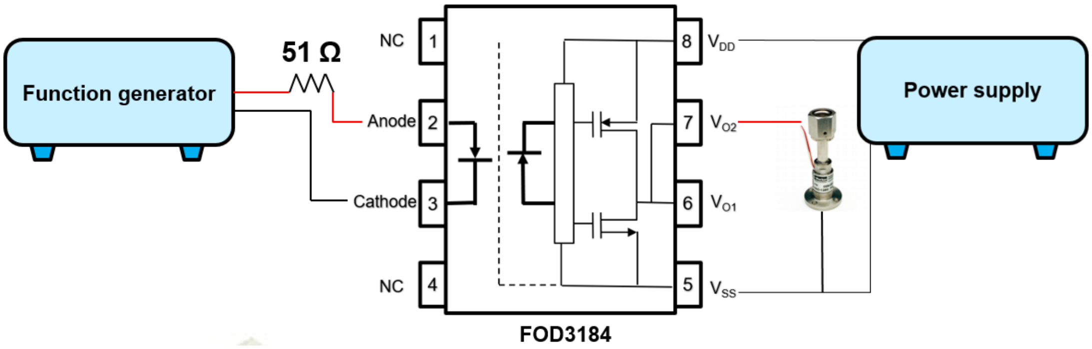


Figure 15: The circuit of the pulse valve working with the time delay signal.

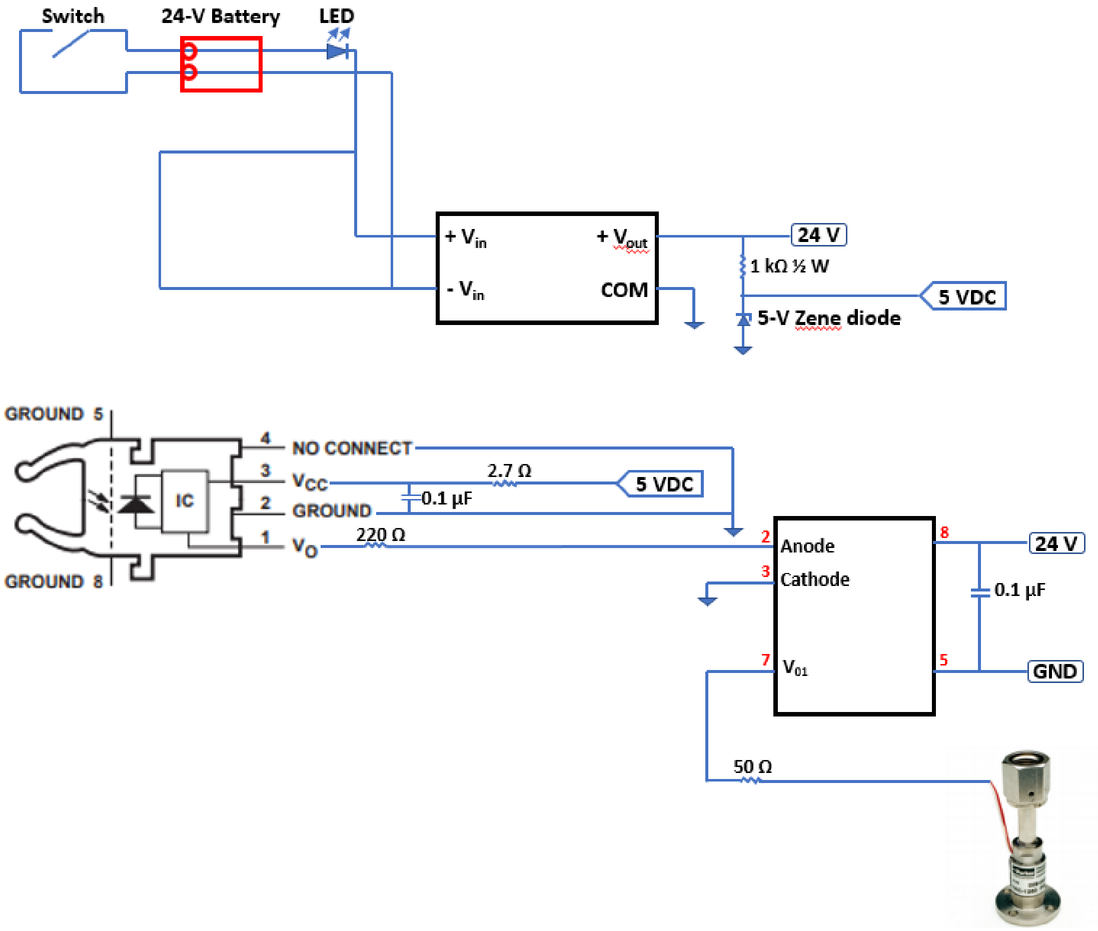


Figure 16: The layout of the pulse valve circuit.

3.4 Experimental results

We first needed to verify the voltage and the pulse width of the pulse. Therefore, we replaced the pulse valve by an oscilloscope as shown in Figure 17. Figure 18 to figure 20 are the output voltage measured with an oscilloscope when square pulses with pulse widths of 5, 4, 3 ms were used as the input signal. The averages of the measured pulse width were 5, 4 and 3 ms which matched with the setting of 5, 4 and 3 ms, respectively.

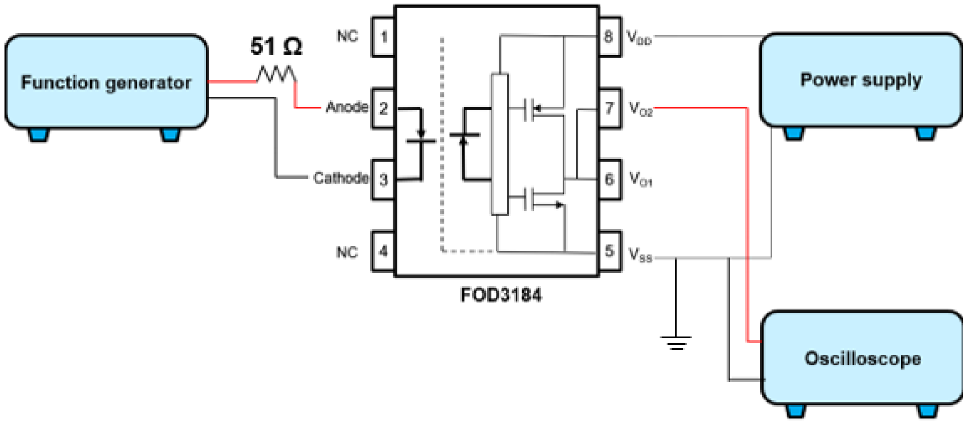


Figure 17: The circuit of the pulse valve measuring with the oscilloscope.

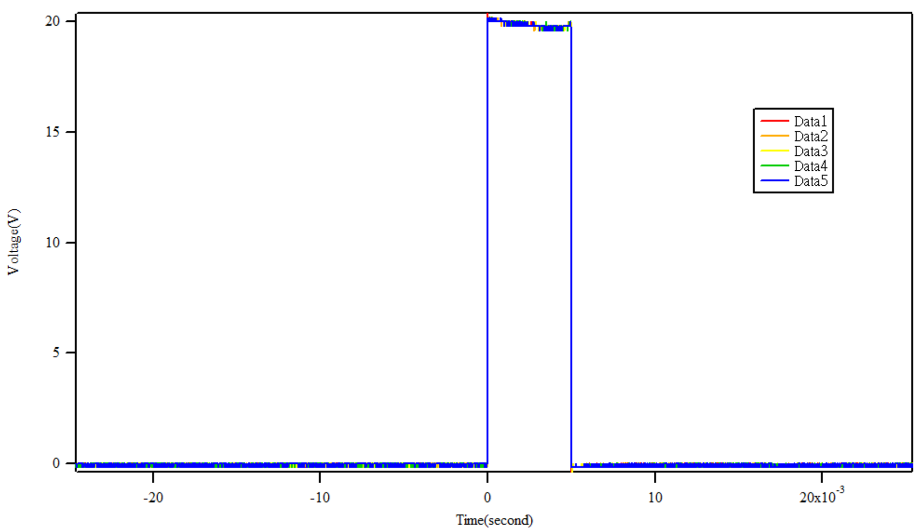


Figure 18: The data of 5-ms width of the square wave for the pulse valve working.

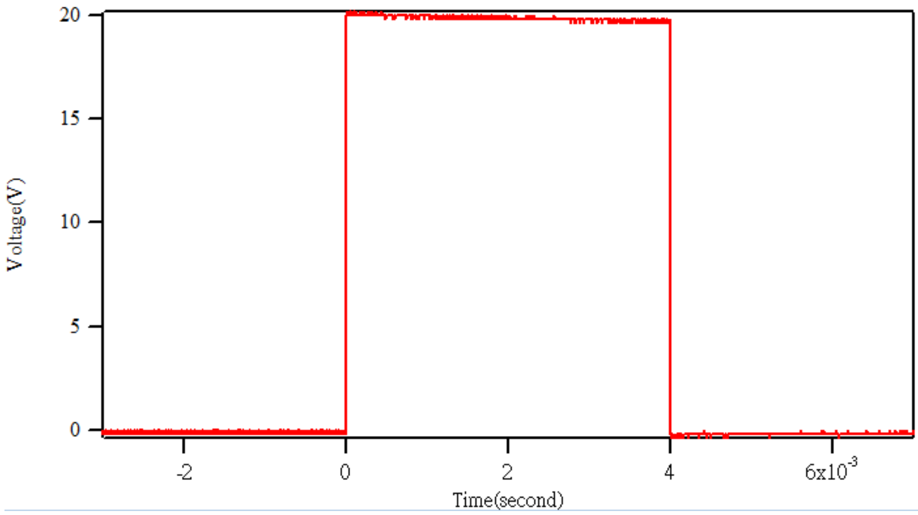


Figure 19: The data of 4-ms width of the square wave for the pulse valve working.

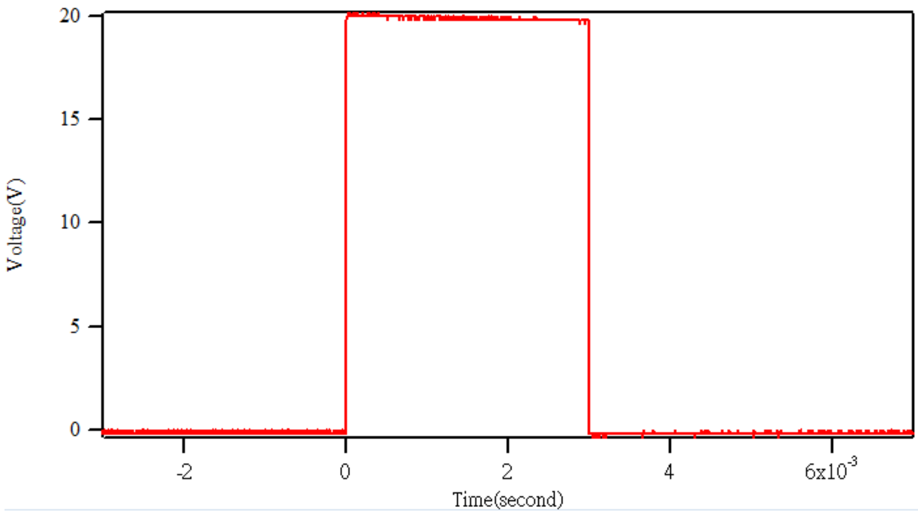


Figure 20: The data of 3-ms width of the square wave for the pulse valve working.

3.5 Pulse valve’s movement detection

The sound of the pulse valve’s movement was used to determine the time that the valve moved. As shown in Figure 21, we used the cellphone to record the moving sound of the pulse valve. The opening and closing peaks were analyzed as shown in Figure 22. We found the width of the square pulse from the function generator wasn’t the actual opening time of our pulse valve. The actual time delay is longer than the width of the square pulse from the function generator.

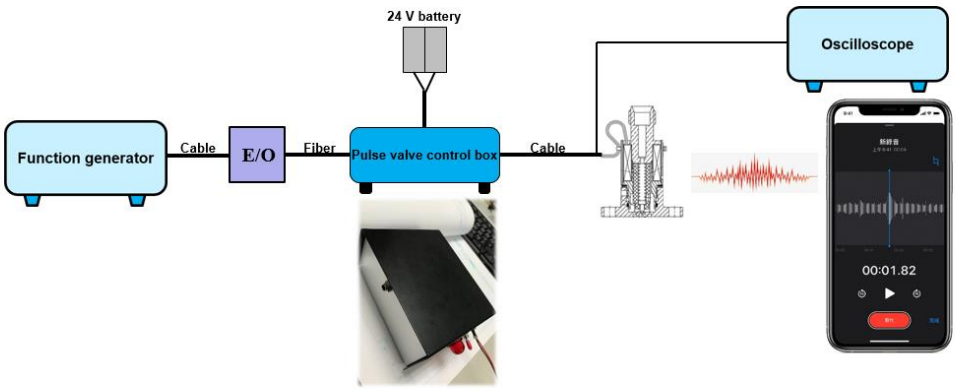


Figure 21: The recording experiment of the pulse valve working sound.

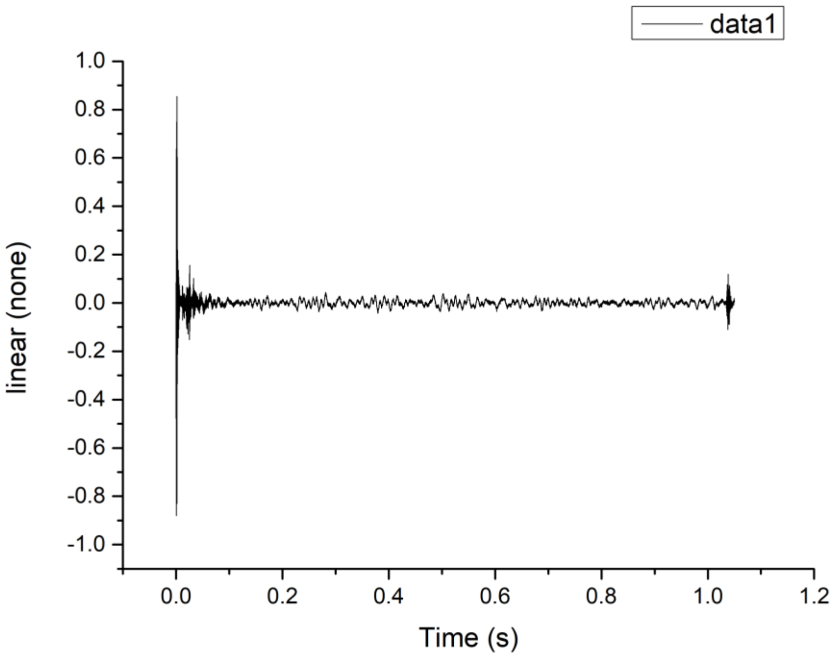


Figure 22: The actual time delay for our pulse valve working on 5 ms.

4 Future works

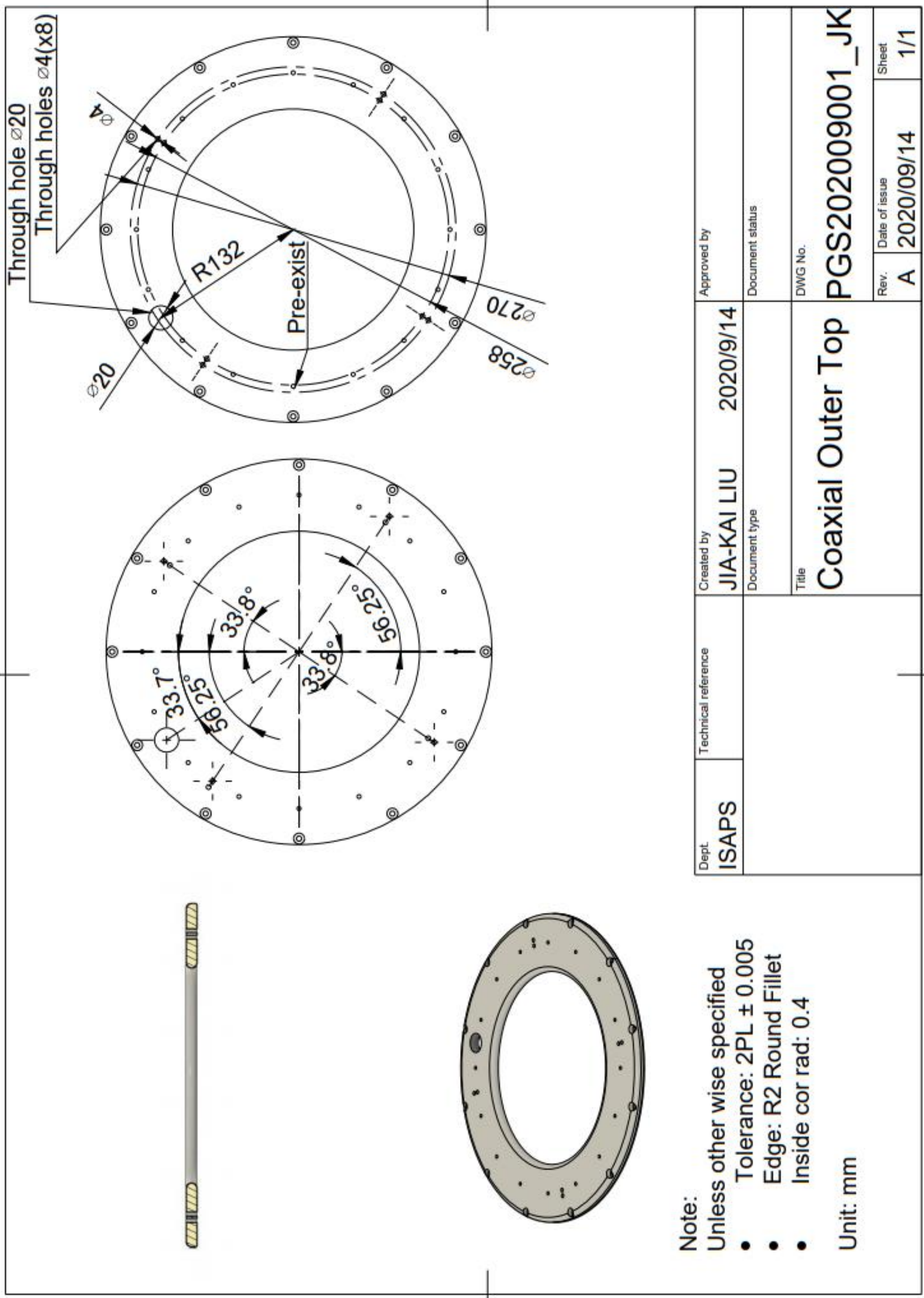
We have finished making and the calibration of the Rogowski coil. In the part of the pulse valve system, we finished the control circuit of the pulse valve. We are going to find the relation between the set opening time and the measured opening time for our pulse valve. The reservoir system will be built and combined with the pulse valve system. The schlieren system will be built to measure the propagating speed of the gas puff.

5 Summary

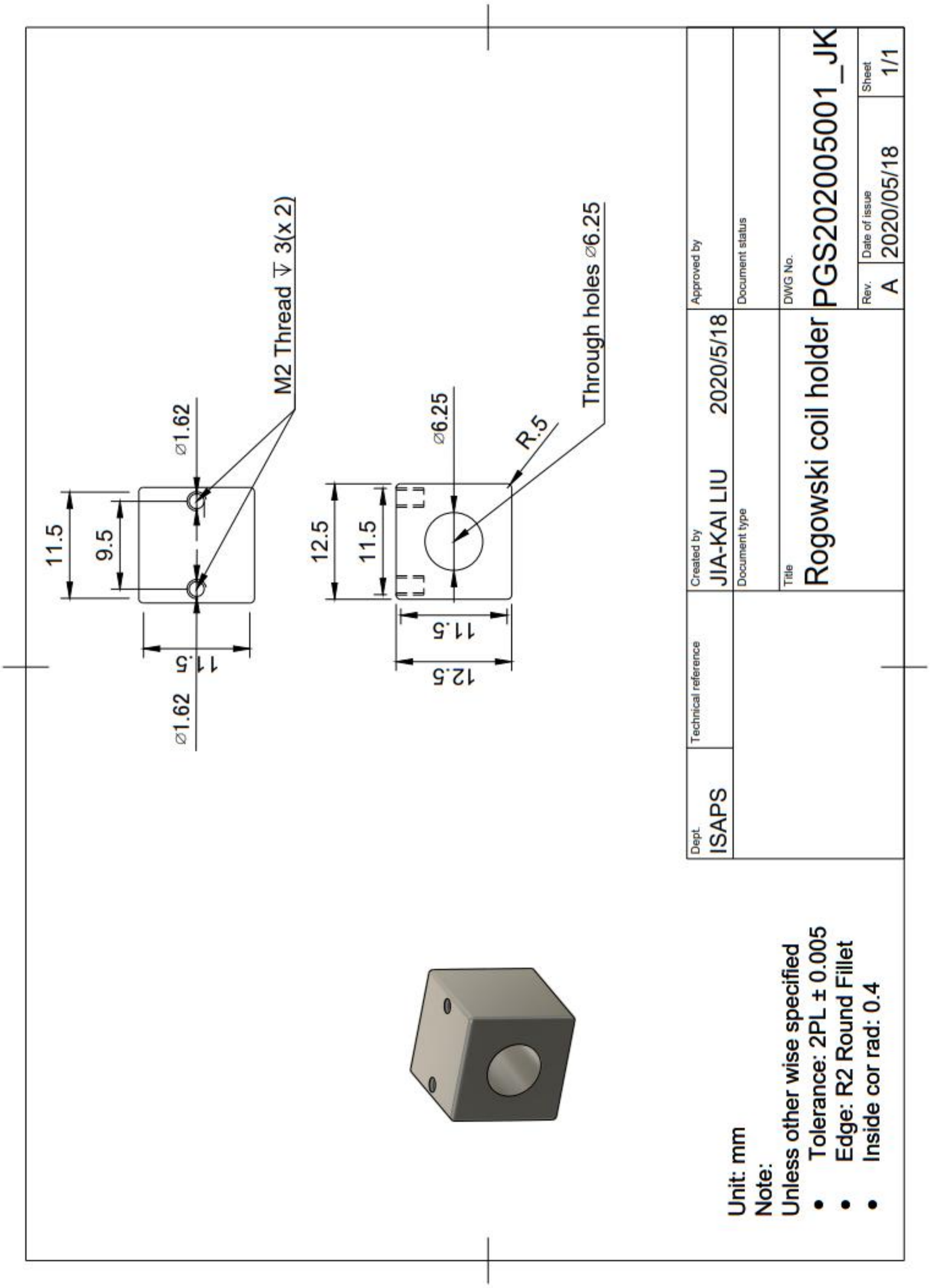
In this report, we have finished setting the Rogowski coil under the top plate of the CTL with cable ties and the calibration ratio of the Rogowski coil was 188000±296 (A / V). On the other hand, the 28-V pulse valve has been compared with the 12-V one, and then the 28-V pulse valve is suitable for my experiment. The circuit of the pulse generator was also built and checked the averages of the measured pulse width were 5, 4 and 3 ms which matched with the setting of 5, 4 and 3 ms. We also detected the pulse valve's movement via opening sound to know the actual time delay is longer than the width of the square pulse from the function generator.

6 Appendix

Rev A. of Coaxial outer



Rev A. of Rogowski coil holder



7 Reference

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