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Cold Plasma Generator Using Economical High-Frequency High Voltage Flyback Transformer With Straight and L-Shaped Needles

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***Abstract*—Cold plasma has long been recognized for its effect which can be used to inactivate viruses and bacteria, both on objects and in the air. In the current state of the coronavirus pandemic, economical plasma generators can play a role in medical handling and room sanitation needs. This study analyzes the use of an inexpensive high-voltage flyback transformer that is easily available in the market and makes use of it to produce a compact cold plasma generator. The flyback is tested by conditioning the frequency variations with the same pulse width. The test results showed variations in the output voltage and ion quantity. The variation of the ionizing needles used also showed that the L-shaped needle produced an anomalous increase in the peak of ions at its best resonance. However, the ions in the L-shaped needle is slightly lower when compared to the variation of the straight needle at the other frequencies.**

Keywords— cold plasma, ion plasma, plasma generator

I. Introduction

Cold plasma is a method of ionizing air that has various benefits, one of which is that it can inactivate harmful bacteria and viruses [1]. Several studies have shown that cold plasma can inactivate more than 99% of harmful viruses, including the coronavirus family, in less than an hour [2] [3]. With its ability to inactivate various germs, plasma can be applied for medical purposes and reduce the risk of virus transmission [4]. Cold plasma will only form H^+ and $O2^-$ which can damage the spike and proteins in the virus so that it cannot infect human cells. Plasma is also relatively safe for humans if it is designed at an ideal output voltage and construction, which will not produce ozone which is toxic in nature [5] [6].

Considering plasma-based ionizers are currently quite expensive on the market, it would be good if there is a construction that can be made by using economical components that can work reliably. On the market, there are types of high voltage flyback transformers which are commonly used as arc lighter. This type of transformer is very economical and easy to get in the market for around $1 USD per piece. This research investigates the use of this type of transformer to be used as an inverter to produce cold plasma by using the common ionizing needle with a straight and L-shaped needle configuration.

II. Aim and Scope

This study aims to test the build of a compact plasma generator using a generic high-voltage flyback single-tube transformer with a ratio of 1: 100 with a frequency rating between 20 to 400 kHz as shown in Fig. 1. Inductance measurement shows the primary coil has an inductance of around 20 μH and the secondary coil is 500 mH. The frequency used in the test is in the range of 35 to 172 kHz with a pulse width of 3 μS.

Fig. 1. Generic single-tube flyback transformer

The making of the plasma generator here uses a power supply without regulation. This aims to simplify the power supply so that it can be reproduced without using a switching regulator. The unregulated power supply is also useful as an accelerator for charging high-voltage capacitors at the onset of pulsation. Tests are then carried out to see the response of the output voltage to frequency variations to determine the optimal frequency. Also, the measurement of ion fluctuations emitted through the tunnel is blown by the blower fan with a variation of straight and L-shaped needles.

III. Research Methods

The high-voltage generator consists of a switching control device that will activate a 3 μS pulsation which can be alternated in frequency using a single microcontroller. The pulse will then activate the driver every 4 seconds alternately. On the unit, the driver will then drive the current to the flyback transformer to produce a high voltage. The driver circuit allows a back-induced electromotive force from the flyback, which able to raises the capacitor voltage in the driver unit and increase the efficiency. The driver for generating positive ions uses a working voltage of 12 V at 1 A, and for negative ions, it uses a higher voltage of 24 V at 1 A. This voltage is selected

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so that the output voltage remains below 6 kV in order to minimize the generation of ozone when ionization is carried out.

In the block diagram in Fig. 2, *D* is used as a high voltage rectifier and is useful for converting the high voltage into the desired electrical pole for ionizing, either positive or negative. The selection of diodes used has a rating of 20 kV / 5mA. *C* is a high voltage ceramic capacitor with specifications of ⩽1.2 nF / 10 kV. The flyback transformer is selected selectively which has the same resistance value at 2.2 kΩ so that both are very close or identical. The electric poles for ionization are then passed on to the joint ionization needle.

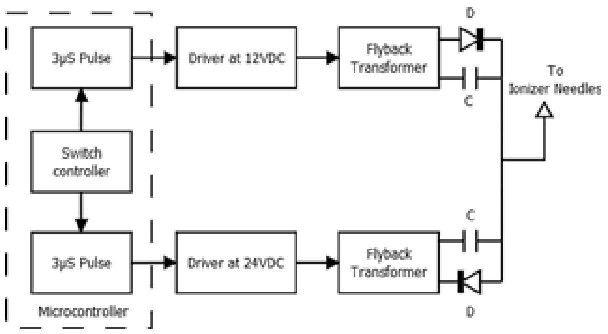

Fig. 2. Block diagram of a cold plasma generator

The joint ionization needle uses a stainless steel needle which has a diameter of 1.2 mm. There are two configurations used later in testing as explained. The first is a straight needle, and the second is an L-shaped needle. Each joint uses 4 needles. The configuration is shown in Fig. 3. The needle is attached to the airflow tunnel that uses blows from a 5 cm centrifugal fan with a speed of 4000 RPM. The lower part of the tunnel has FR4 laminated material where the needles soldered., while on the sides and top use 3D printed PLA as cover.

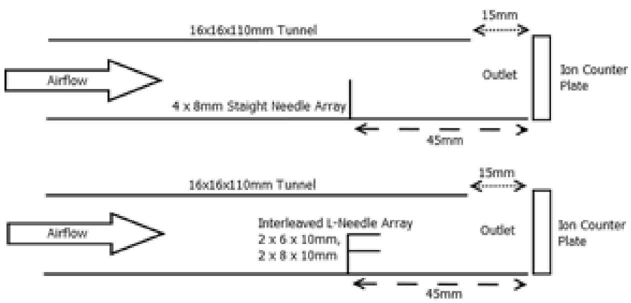

Fig. 3. (top) tunnel with straight needles, (bottom) tunnel with L-shaped needles

Unless The test is then carried out by attaching the counter ion plate (KT-401 instrument) to the outlet, while the grounding plate on the instrument is connected to the ground. Ion measurement is done by reading the maximum ion fluctuation value in each positive and negative mode. The peak voltage measurement is performed using a 1000: 1 high voltage probe connected to a digital voltmeter (DMM) with an input impedance of 10 MΩ. The input current and voltage on the driver will also be measured because there will be a variation in voltage when the flyback pulsation. It can either be lower due to excessive power consumption, or it can be higher due to the diode bypass in the driver to the back electromotive of the flyback.

Furthermore, ozone production testing is conducted to assess the safety of ozone production that may arise from air ionization. Testing using a digital ozone level measuring and recording device with a resolution of 1 ppb. The first test is to place the measuring device directly in front of the tunnel outlet in an open space to see the production level directly in 10 seconds. The second test uses a 30x20x25cm impermeable glass box to measure the accumulated ozone level within 1 hour as illustrated in Fig. 4.

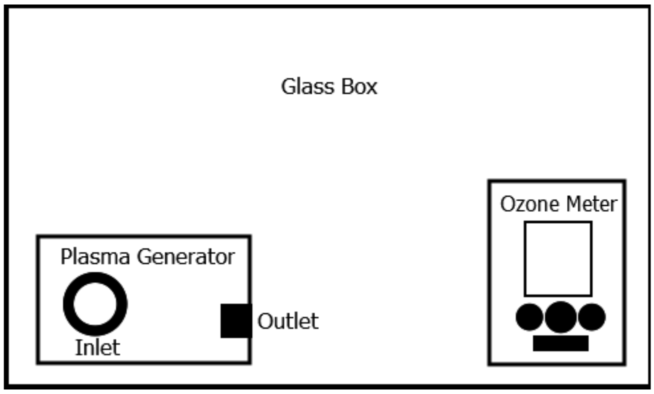

Fig. 4. (top) tunnel with straight needles, (bottom) tunnel with L-shaped needles

IV. Results and Discussion

The measurement results are obtained by running the device at different frequency modes then measuring the input current and voltage, the high voltage output, and the ions generated at the outlet. The results can be seen in Table 1, Table 2, and the output voltage plotted as Fig. 5. Input and output voltages vary with each frequency. The first peak resonance of the flyback is at 44 kHz and the second peak resonance is at 86 kHz. Above a frequency of 86 kHz, the efficiency and voltage ratio starts to decrease significantly. In comparison, the positive output voltage generated from the primary voltage can be higher than the negative voltage output. The voltage at the resonant peak at 44 kHz reaches 1: 249 for positive voltages, whereas only 1: 184 for negative voltages is obtained.

TABLE I. Negative Voltage Generator Measurement

Frequency (kHz)	**Input Voltage (Volt)**	**Input Current (Ampere)**	**Power (Watt)**	**Output Voltage (-kV)**
35	26.0	0.15	3.9	4.69
39	23.7	0.26	6.162	4.14
44	23.3	0.25	5.825	4.29
51	22.3	0.27	6.021	3.3
59	19.4	0.40	7.76	2.73
70	24.8	0.17	4.216	3.72
86	22.5	0.26	5.85	4.15
119	15.6	0.56	8.736	3.21
172	9.4	0.92	8.648	1.61

The measurement results of ion emission fluctuation for both straight and L-shaped ionizing needle configurations can be seen in Table 3 and Fig. 6. At other frequencies, the use of the L needle has a slightly lower ionic fluctuation than the straight needle. But at the first peak resonance, it produces a peak ion fluctuation anomaly that is much higher than that of a straight needle. There is a difference of 0.77 million ions / cm³ between them. Although it can produce a higher measured ion output at a frequency of 44 kHz, the ion output on the L-needle is still lower when compared to a straight needle at the second resonant frequency (86 kHz) which has a difference of 0.33 million ions / cm³. This is also because the first resonance produces a lower negative voltage difference of 0.49 kV, while the second resonance produces a higher difference of 0.62 kV. This indicates that an L-shaped needle has the potential to increase the ion output at the first resonance, and it is better to prefer using a straight needle at other frequencies.

TABLE II. POSITIVE VOLTAGE GENERATOR MEASUREMENT

Frequency (kHz)	Input Voltage (Volt)	Input Current (Ampere)	Power (Watt)	Output Voltage (+kV)
35	20.3	0.09	1.827	4.12
39	16.5	0.32	5.28	3.59
44	19.2	0.14	2.688	4.78
51	17.3	0.24	4.152	3.37
59	15.5	0.29	4.495	3.76
70	20.0	0.10	2.0	4.06
86	18.8	0.16	3.008	4.77
119	12.9	0.51	6.579	3.7
172	7.0	0.88	6.16	1.89

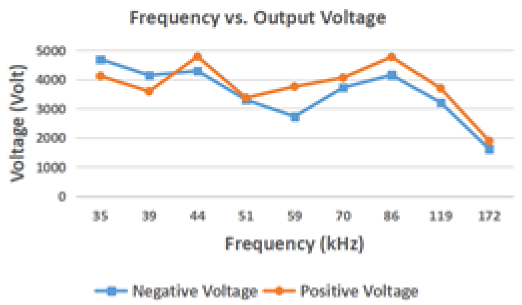

Fig. 5. (top) tunnel with straight needles, (bottom) tunnel with L-shaped needles

TABLE III. ION MEASUREMENT RESULT

Frequency (kHz)	Maximum Ions Reading (million ions / cm³)	
	Straight Needles	L-Shaped Needles
35	0.69	0.62
39	0.24	0.18
44	3.72	4.52
51	0.11	0.08
59	0.27	0.21
70	1.2	1.18
86	4.85	4.76
119	0.14	0.1
172	0.13	0.11

The results of the ozone level test can be seen in Table 4. From all tests, both direct testing in front of the plasma outlet and cumulatively in one hour in a closed glass box, the measuring instrument did not detect the presence of ozone, or its level was confirmed to be less than 1 ppb. For that, the cold plasma produced is safe to use. Of course, for that, an adjustment must be made to the positive input voltage so that it is equal to or lower than the negative voltage. This is due to the need to balance the emitted ions so that the negative ion effect does not arise in practice. This can be done by turning down the input voltage for the positive ion emitter. Another way is to use a diode on the driver to prevent the reverse electromotive effect, but of course, it has the potential to reduce the efficiency of the generator device.

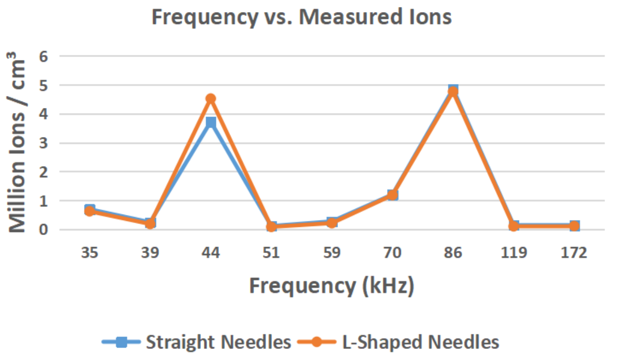

Fig. 6. Comparison of ion measurements between straight and L-shaped needles

TABLE IV. OZONE LEVEL MEASUREMENT RESULTS

Frequency (kHz)	Direct Outlet Measured Ozone Level		Cumulative Measured Ozone Level in a hour	
	Straight Needles	L-Shaped Needles	Straight Needles	L-Shaped Needles
35	Undetected	Undetected	Undetected	Undetected
39	Undetected	Undetected	Undetected	Undetected
44	Undetected	Undetected	Undetected	Undetected
51	Undetected	Undetected	Undetected	Undetected
59	Undetected	Undetected	Undetected	Undetected
70	Undetected	Undetected	Undetected	Undetected
86	Undetected	Undetected	Undetected	Undetected
119	Undetected	Undetected	Undetected	Undetected
172	Undetected	Undetected	Undetected	Undetected

V. CONCLUSIONS

This study concludes that the economical single-tube flyback used can be used to produce cold plasma ion generators safely without causing any harmful ozone side effects. The positive high voltage will be easier to generate and have a higher output ratio than the negative high voltage generation even though it has used half of the negative input voltage. To anticipate this, it is necessary to adjust for a positive input voltage or by bypassing electromotive force feedback with the risk of decreasing efficiency. This is necessary to adjust the output voltage and the ion balance. The use of an L-shaped ionizing needle will result in much higher ion fluctuation than applying a straight needle at the peak of the first peak resonance of the transformer, but slightly lower than a straight needle at other frequencies.

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