Plasma Generator for Testing Vacuum Integrity of Evacuated Vials

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***Abstract*—**This paper presents the Experimental Study of Plasma Generation which is used for ensuring quality of Evacuated Vials (Vacuum vials), using an electronic circuitry making it safe and much more economically feasible. Evacuated vials are widely used in Pharmaceutical Industries. Reliable test of the batches of Evacuated Vial must be done before dispatching these for the use of customer. There can be problems involved in checking of these vials, as the conventional devices are either unsafe or expensive. There are numerous methods for Generation of Plasma, among which our experimental study is based on RF Corona Discharge method for achieving Experimental Output. In this demonstration evacuated vials have being exposed to high frequency high voltage which creates a large Electric Field. Due to this field electron-positron pairs are produced in vacuum thus making it electrically conductive. Due to phenomenon of Corona Discharge a Violet Spark is observed in the vial, this violet spark is only the plasma. This demonstration can be used to confirm presence of sufficient amount of vacuum in the vial.

Keywords*-*Evacuated Vials, Vacuum Vials, Plasma Generator, Corona discharge, High Voltage High Frequency, Resonant transformer, DRSSTC.

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I. INTRODUCTION

BRIT is an industrial unit of Department of Atomic Energy and deals with Radioisotopes Application. According to the survey done by NICPR (National Institute of Cancer Prevention and Research) estimated number of people living with the cancer disease is around 2.5 million. Every year over 7 lakh new cancer patients registered and around 5,56,400 numbers of people have to face cancer related deaths.There are various advancements in detection and cure of Cancer among which Radioactive medicines are nowadays widely used. In this technique radioactive substance along with a substrate is injected into the patient's body to either detect or treat the cancer in any parts of the body. Now to inject this radioactive medicine, it is of immense importance to prepare the medicine freshly on the spot as the medicine may undergo decay if stored. For this purpose pharmaceutical companies come up with a product which includes a Generator Refer [Fig 1] along with few vacuum vials. These generators are designed such a way that they produce radioactive medicine which must be extracted into a vial for further use. This is done by the use of vacuum vial. Due to the pressure difference, the medicine is sucked into the vial. This vial is concealed in a lead container as a result of which it isn't visually possible for the doctors to check if the medicine is being collected in the vial or not. Hence presence of sufficient vacuum in the vial is of utmost important and one of the method to determine vacuum inside vial in a non-destructive way is a "RF Corona Discharge Technique [3].

High-voltage plasma generation is widely used in industry applications, such as static charge remover, ozone generator for sterilizing, plastic and metal surface imprinting processing,Etching process in VLSI Industry and so on.Corona discharge is a process by which a current flows from an electrode with a high potential into a neutral fluid, usually air, by ionizing that air so as to create a region of Plasma around the Electrode. The ions generated eventually pass charge to nearby areas of lower Potential, or recombine to form neutral gas molecules. This corona discharge which forms a region of plasma is difficult to achieve at Atmospheric Pressure due to more number of Gas molecules present in it, which requires a Higher Electric Field strength of about $3*10^6$ V/m or 3 KV/mm [1], if we use an vacuum which refers to any space where pressure is lower than atmospheric pressure.The quality of a vacuum is indicated by the amount of matter remaining in it. Thus the amount of electric field required is less and plasma can be generated easily. Thus in this demonstration when we keep the Evacuated Vial under a high electric field, Corona discharge takes place which forms a region of plasma in the vial and this formation of Plasma ensures presence of vacuum.

Fig 1 : Generator Dispatched to Doctor.

II. PROBLEM STATEMENT

Medicines for cancer detection and vacuum vials are manufactured in BRIT. Vacuum vials play a very prominent role in handling these radioactive medicines, as they cannot be handled by bare hands. These medicines are extracted from their generators to the evacuated vials by pressure difference mechanism. As evacuated vials are at low pressure than atmosphere, medicine is sucked inside the vial. Hence quality assurance of these vacuum vials is of immense importance. The conventional device used at BRIT was based on spark gap technology and caused high EM noise. The device currently used is imported and is Expensive.

The aim is to design and develop an electric circuit based Plasma Generator for ensuring quality of evacuated vials. The device should be user friendly and economically feasible which can be easily maintained & debugged.

III. METHODOLOGY

The high voltage generation techniques are Voltage multiplier, transformer in cascade and resonant transformer. One of the simplest method for generating high direct voltages is voltage multiplier. It is similar in many ways to a rectifier which converts AC to DC. Here combination of rectifier diodes and capacitor is used together to effectively multiply the input AC voltage to give a DC output equal to odd or even multiple of peak voltage value. This is normally used in Microwave oven where the output of primary transformer is doubled to drive the wave generator Magnetron. The technique of connecting transformer in cascade are used to generate a very high AC voltage, up to 100KV-500KV, which is used in high voltage laboratory for insulation testing purpose. These two techniques are generally not used to generate plasma as the operational frequency is low. Thus Resonant transformers are used as they are capable of producing very high AC voltages of High Frequency and low current which is desirable for RF Corona Discharge and also improves Plasma Quality due to high frequency operation.

A. Reaonant Transformer

*1) Spark Gap Tesla Coil:*Tesla coil works on the principle of electrical resonance. The primary is supplied through a capacitor C1. A spark gap G is connected across the primary winding which can be triggered at a desired voltage Refer [Fig 2] . The primary and secondary coils form two resonance circuits [2]. As the current oscillates at resonance frequency through the primary coil the oscillating magnetic field created in the primary coil induces an oscillating current in the secondary coil by Faraday's law of induction since the two coils circuits are tuned to the same resonance frequency and the energy in the primary circuit is transferred to the secondary circuit [2]. The oscillating voltage in the secondary circuit increases in amplitude and a very high voltage is obtained at the secondary end.The energy dissipated in the spark also reduces the Q factor and the Output Voltage.

2) Single Resonant Solid State Tesla Coil (SRSSTC): SRSSTC is similar to spark gap tesla coil,here the primary does not have a capacitor so it is not a tuned circuit. the spark gap which is responsible for producing oscillation is replaced by an semiconductor switch Q and diode D Refer [Fig 3]. SRSSTC is simpler to design but don't have a high Q factor and cannot produce higher voltage from a given input power as the DRSSTC.

3) Dual Resonant Solid State Tesla Coil: In this experimental study the concept of dual resonant solid state tesla coil is used. A DRSSTC is similar to spark gap tesla coil which has capability of producing high voltage high frequency at low current. This DRSSTC is used to replace the disadvantages of the traditional Tesla coil. Here the spark gap which is responsible for producing of oscillation is replaced by electronic circuit which consists of semiconductors switches like transistors and several diodes. Also this dual resonant solid state Tesla coil can be used just by plugging in to conventional ac mains or a dc battery. Here the primary and secondary resonant can be easily achieved as the oscillating frequency is decided by the user itself. It can generate higher voltage for a given input power as it has higher Q factor than the SRSSTC.

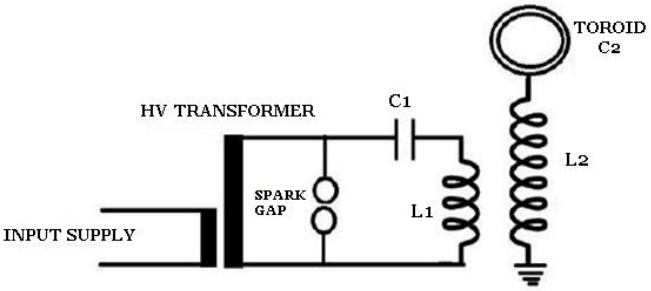

Fig 2 : Spark Gap Tesla Coil

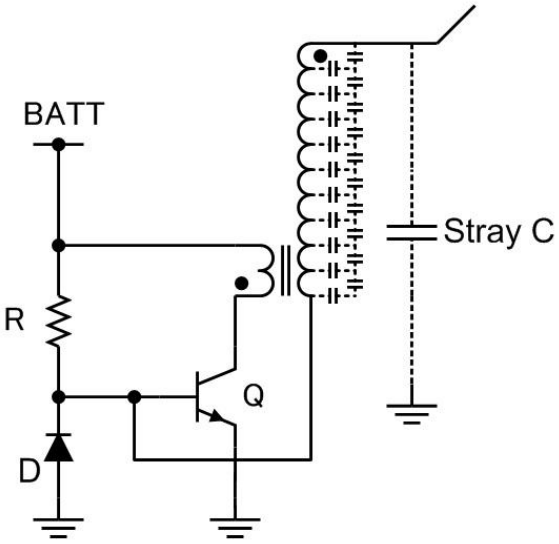

Fig 3 : Single Resonant Solid State Tesla Coil

B. Block Diagram

To understand the working of device, circuit can be explained in blocks. First block is power supply unit. This unit incorporates AC to DC conversion unit. It is comprised of a 230 V to 120 V and 12 V dual voltage step down transformer. This AC supply voltage is converted to DC voltage by bridge rectification unit. Voltage regulators are used to get +5 V and +12 V DC. +170 V DC is given to the primary of tesla coil and +5, +12 V are used to provide Vcc to electronic circuitry. Next is an Internal Oscillator block. 7405 type integrated circuit is

used to drive the crystal of 4MHz. Along with driving the crystal, IC 7405 is used to reshape the sine wave into a square wave. At the output standard square wave of 12V p-p is obtained. This signal is then fed to the next block which is a MOSFET gate driver. The MOSFET gate driver is required to drive the highly capacitive load of the MOSFET gate terminal at MHz Frequency. The load to the MOSFET is primary coil of Dual Resonance Solid State Tesla Coil (DRSSTC) which is connected at its drain. Indigenization is possible when we have a coil that is well designed such that it self resonates at a frequency of 4MHz.

While using devices that operate at high voltage ranges, proper protection must be taken. Therefore in the circuitry a fault protection module is designed for user's safety. Fault protection circuit is based on comparator integrated circuits. This module protects the switching circuitry by cutting off driver's signal either if MOSFET's VDS increases above 190V or its drain current increases above 1A. The reference voltages given at the comparator IC's can be adjusted according to the threshold voltage above which circuit is to be ceased. To make the device more reliable the hysteresis is added for false triggering protection.

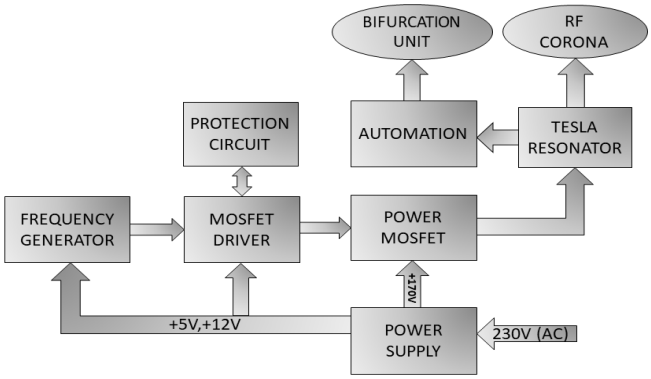

Fig 4 : Dual Resonant Solid State Tesla Coil

C. Designing of Tesla Resonator

The Advantage of DRSSTC is that both the coils resonate at the same frequency which is desired by the user itself, in this case which is 4MHz. This is useful as maximum power transfer takes place generating a very high voltage at a given input power. The resonant frequency is given by the formula given below

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

Where; f is Resonant Frequency in Hz, L is the Inductance of the coil and C is the Capacitance of the coil.

The inductance is given by

$$L = \frac{N^2R^2}{9R+10H} \quad (2)$$

Where; L is Air cored solenoid inductance in µH, N is number of turns, R is radius of coil in mm and H is the height of the coil in mm.

And capacitance is given by

$$C = \frac{0.29H+0.41R}{25.4} + 0.0763\sqrt{\frac{R^3}{H}} \quad (3)$$

Where;C is self-capacitance of coil in pf, H is the height of the coil in mm and R is the radius of coil in mm.

For the designing of primary coil both L and C are controlled parameter for the user the frequency chosen here, it is 4 MHz, but when it comes to secondary coil the secondary capacitance is an parasitic capacitance which depends on the environmental conditions which is usually between 1pf to 100pf so only secondary inductance is in control of the user. Thus to achieve a proper resonance the primary coil should be moved upward or downward aligned with the secondary coil and the output should be interpreted by the intensity of the CFL bulb, at the maximum intensity it can be concluded that resonance has been achieved.Normally primary coil should have lower gauge as the current flow through it is much higher than secondary.

IV. EXPERIMENT

A prototype was designed using a Single Resonance Solid State Tesla coil. The secondary of the coil was designed to be oscillated at 4MHz frequency. As electric field cannot be seen by eyes, one of the ways to demonstrate the presence of electric field is by witnessing generation of plasma in CFL Bulb Refer [Fig 5].The intensity of the bulb indicates the amount of power transferred. To achieve the resonance primary coil is moved up or down, when the bulb glows with higher intensity it can be concluded that maximum power is transferred. Also while working with Radio Frequency circuits the Ground plane is utmost important.

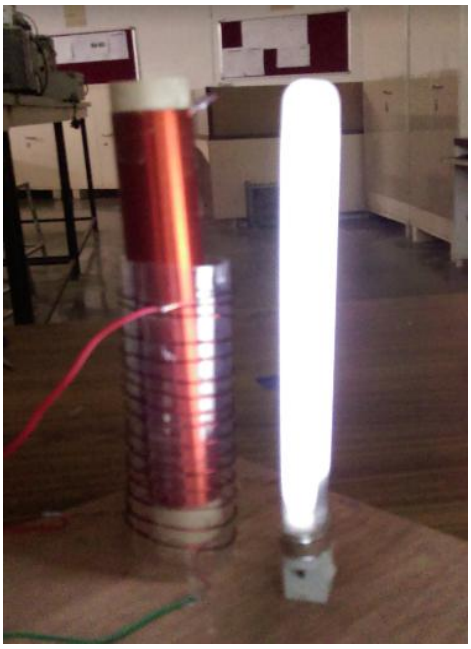

Fig 5 : Generation of Plasma in CFL

V. AUTOMATION

A. Corona Discharge Test

This test is used for leak detection in lyophilized products that have been evacuated, or other container systems that have been filled under vacuum. The corona discharge test may be performed manually or automatically. For the manual test, a high voltage/ high frequency electrode is applied to the outside of the vial. The operator inspects the vial for the presence of a corona discharge (Plasma Formation) caused by the ionization of the gas molecules in the headspace. If the glow does not appear, the operator can adjust the voltage and retest the vial. If the retest fails, the vial is rejected. The corona discharge test can be automated in this case the inspection system applies the high voltage high frequency field across the vial headspace while measuring the current across the electrodes. If no current is detected, the vial is rejected [4]. For controlling the automated system a proper isolation has to be provided to the micro-controller, this can be done by placing the controller at the bottom of the Tesla resonator also the controller must be placed in Faraday cage to avoid the electrostatic discharge. Factors affecting the corona discharge test include test voltage, vacuum level (too low a vacuum level may affect the efficiency of the test because of the absence of gas molecules to ionize), Vial geometry & Environmental conditions [4].

VI. ANALYSIS & OUTPUT

To analyze an activity, one parameter should be constant and other should be varied accordance to the constant parameter. These evacuated vials were scrutinized by suspending them in constant electric field where time is the varying parameter. According to the amount of molecules present inside the vial, it took different amount of time to ionize the molecules. A batch of vials was tested and an average time of 15sec. was decided to be the test time. It was also observed that as testing of vials was delayed, it took longer time to ionize them meaning that vacuum leaks as they are not sealed. Therefore it is advised that for better utility, vials should be tested when freshly prepared and must be sealed properly.

A. Observations

Following are the Observations that came across in the Experimental study.

TABLE I. ANALYSIS OF VIALS SUSPENDED AT HIGH ELECTRIC FIELD

Sr. No.	Voltage without Vial [mV]	Voltage with Vial [mV]	Output Voltage [mV]	Time [Sec]	Accept/ Reject
1	190	160	125	14	Accept
2	191	155	121	15	Accept
3	195	146	146	35	Reject
4	190	135	120	2	Accept
5	193	132	121	10	Accept
6	196	134	122	3	Accept
7	193	138	180	3	Accept
8	190	142	121	6	Accept
9	191	130	115	1	Accept
10	197	132	116	2	Accept
11	195	135	118	1	Accept
12	190	140	141	30	Reject
13	191	130	115	6	Accept
14	196	130	115	5	Accept
15	192	136	114	11	Accept

When vials are suspended in High Electric Field, a significant voltage drop is observed on the input side of the circuit. This voltage drop can be used to generate an signal, which can be further use to automate the whole system. It can be seen that the observed output voltage is almost the same for the vials which are properly evacuated. As time is the varying parameter the quantity of the vacuum level can be interpreted by the time required to ionize the molecule, the vial which required less time has better vacuum level than the one which requires higher time.

B. Output

Due to capacitive property of human body, the hand can be used as a GND Electrode. Refer [Fig 6].Also carbon brush can be used as a GND electrode which can be used in mechanical model. The amount of plasma observed in the freshly prepared vial Refer [Fig 7]. Plasma observed in vial which has been delayed in checking Refer [Fig 8]. The below Three figure indicates generation of plasma which ensures presence of vacuum in vial.

Fig 6 : Using Hand as GND Electrode

Fig 7 : Plasma in Freshly Prepared Vial

Fig 8 : Plasma in Sealed Vial

VII. Conclusion

Presence of Vacuum in the evacuated vials can be assured by generation of plasma. Energy required for the same can be provided in the form of electric field using Tesla coil. Because of use of frequency in RF range, chances of electrocution are eliminated, but it may cause RF burn on coming in contact with Tesla coil. As large electric field is produced at the free end of Tesla coil, it may cause interference in small signal devices if kept in the range of Tesla coil. To avoid absorption of generated electric field, body of the product is made of Acrylic. This device is cost effective.

VIII. Acknowledgement

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