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Experimental investigation of vircator by DC discharge

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ABSTRACT

A vircator powered by DC power supply has been designed , operated and tested. The discharge is between mesh anode and disc cathode. It has been found that the discharge is in the up-normal glow discharge and also follows Child law. Experimental studies showed that the optimum spacing between the mesh anode and disc cathode is 3.5 mm at the adopted spectrum. The discharge current variation with the spacing between electrodes has a peak value of 20 mA at 3.5 mm for the same applied voltage and gas pressure. Several microwave frequencies radiated from the system have been observed. The radiated power for the different frequencies has a peak value at nitrogen gas pressure of 0.7 Torr and 3.5 mm electrodes spacing.

KEY WORDS: Vircator, DC-Discharge, Microwave Frequency

I-INTRODUCTION

One of the classic applications of electron beams is the generation of coherent electromagnetic radiation. The development of sources of radiation in the high power microwave portion is within electromagnetic spectrum but it is classified as plasma devices. However, an impressive increase in the power and operating frequencies of these sources has taken place in the last few decades [1]; due to progress in a new branch of physics that can be called relativistic high frequency electronics which is very tight to plasma microwave generation physics [2]. The progress results from three main developments. Firstly the use of higher voltages and currents in conjunction with conventional microwave device concepts, such as klystrons and magnetrons. Secondly the development of new device concepts that rely specifically on very high currents, such as vircators. And thirdly is the research into fast wave devices, such as gyratrons and free electron lasers, that make direct use of relativistic effects, and extrapolate to higher powers at shorter wavelengths than conventional devices [3]. The main mechanism of vircator is the formation of virtual cathode and electron beam for the cathode, which penetrate the formed plasma to generate microwave. Several authors [4-7] have presented theoretical studies of vircator. The vircator consists of mesh anode and disc cathode in plane geometry each, and some other coaxial geometry are used. Virtual cathode is unstable region of negative potential which reflects electrons back into the source between the real and virtual cathodes [8].

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Oscillations in the virtual cathode and harmonic generation associated with that region and reflection of coherent electrons cause the higher frequency components. Oscillations of electrons between the virtual cathode and mesh anode generate microwaves with frequency lower than those of the electron beam interaction with the plasma [9]. Possible mechanisms for excitation of electromagnetic waves in virtual cathode systems were Studied by Kitsanov et.al [10]. They found that the microwave efficiency of double-gap vircator can be higher than that of single gap. Simulation of the vircator behaviors and energy exchange between the electron beam and the RF field, for single and double-gap in 1-D and 3-D, were presented using the KARAT fully electromagnetic PIC code. Simulation of dual-coaxial vircator, without external magnetic field had been carried out by Yang and Ding [11]. They found that by applying a voltage pulse of 500kV, the emitted microwave power will reach a peak value of 2.5 GW, with 11% efficiency. In this study 0-50 kV DC power supply is connected to a vircator which consists of a stainless-steel mesh anode and disc cathode. Experimentally studies are presented for the generation of microwave from DC discharge under different conditions, and also to measure the output microwave power and frequency. Electrons emitted from the cathode will be accelerated towards the anode mainly without collisions. Hence it will cross the anode and undergo collisions outside the mesh anode. Such collisions will produce plasma sheath acts as a virtual cathode.

II-EXPERIMENTAL SETUP

The virtual cathode oscillator (vircator) is developed and designed. The schematic diagram of its electrical circuit arrangement is shown in figure (1). The output of high voltage DC power supply is connected to the two electrodes where the mesh anode was at positive potential with respect to the disc. The disc cathode is 4-cm-diameter cathode made of copper connected to screw bolt long head that screws into a nut used to fasten the cathode with 1 mm pitch for one complete turn of the screw bolt. This system is used to adjust the distance of the cathode inside the housing between 0.5 mm to 6.5 mm. This controls and adjust the anode- cathode gap distance(A-K), since the mesh anode is at fixed position in the housing of the vircator. The mesh is surrounded by two flanges centered inside a 12-cm inner diameter housing 17-cm longitudinal distance made from stainless steel. The metallic steel mesh anode is made from wire with thickness 1mm and with 60 holes/m² with overall diameter 12 cm. Two ports are made at the mid axial sides of the vircator with 5 mm diameter and 2mm thickness. The ports are connected to the vacuum pump system and monitoring thermocouple vacuum gauge. To adjust the pressure inside the cylindrical housing needle valve is used to calibrate continues flow of working gas.

Calibrated voltage and current meters have been used for the diagnostics of the vircator discharge characteristics. The detection of the generated microwave frequencies are carried out by AGILANT frequency analyzer. The frequency range of this study is 200 MHz - 2 GHz. A linearly polarized wide band log-periodic antenna is designed and constructed from lightweight corrosion- resistant aluminum to afford this frequency band, another type of antenna is used up to 13 GHz.

III-EXPERIMENTAL RESULTS

The variation of the discharge current with the voltage between the mesh anode and disc cathode at pressure 5×10^{-1} Torr is shown in figure (2). The I-V curve showed that the discharge is similar to that of the abnormal glow discharge between two solid electrodes. The difference between this discharge and the abnormal glow DC discharge is the neutral atoms which are ionized outside the two electrodes. Since the electrons are accelerated by space charge, it has been found that the I-V curve followed Child law [12],

$$I \propto V^{3/2}$$

where: V is the accelerating voltage and I is discharge current.

The dependence of the breakdown voltage on the gas pressure (p) multiplied by the electrodes spacing (d) is shown in figure (3). The curve is similar to Paschen curve where at low pd higher voltage is required for

breakdown. At left hand side of Paschen curve when pd increased the breakdown voltage decreased, till reach a minimum value. The minimum breakdown voltage about 450V at Pd 1.75 Torr . mm. For the right hand branch the breakdown voltage increases slowly with the increase of pd i.e. the ionization cross section increases, therefore electrons need more energy to ionize the neutral atoms. The operation condition has to be in the left hand side of Paschen curve [13]. The maximum electron beam current depends on the mesh anode and disc cathode (A-K) gap distance. The A-K gap spacing has been changed from 0.5 mm up to 6.5 mm, and measure the discharge current, keeping the gas pressure at 5×10^{-1} Torr, and constant applied potential at 2.5 Kv DC voltage , Figure (4). It has been found that the discharge current increases with increase of gap distance until it reach its maximum, 20mA, at spacing of 3.5 mm. The increase of the discharge current from 1 mm up to 3.5 mm may be due to the increase of the electrons velocity while the decrease of the current after 3.5 mm can be due to the increase of electrons collision probability with neutrons, which reduce the electrons velocity.

Figures (5,6,7) are samples of the measured variation of the emitted frequencies at different conditions which is in agreement with the electrical parameters of the discharge. Radiated microwave amplitude versus A-K gap of the vircator has been investigated at different frequencies from 200 MHz up to 500 MHz for working gas pressure 5×10^{-1} Torr figure (8). It has been found that the maximum amplitude at $d=3.5$ mm for all observed frequencies. Figure (9) shows the radiated microwave amplitude variation with working gas pressure for A-K spacing of 3.5 mm. It has been found that radiated microwave amplitude voltage had a peak value at 7×10^{-1} Torr, for all the investigated frequencies.

IV-Conclusion

Vircator with stainless- steel mesh anode and copper disk cathode is presented. The vircator is powered by DC power supply 50 Kv. The I-V characteristics shows that the discharge is within the up normal glow discharge and follows Child law. Pd relation with discharge voltage is obtained which is typically Paschen curve. It is found that electron beam discharge current varies with the anode cathode (A-K) spacing, where it reached its maximum value at 3.5 mm. The microwave output is dependent on the anode cathode (A-K) gap distance, where the optimum spacing which gives the maximum output microwave power is of the order 3.5 mm over frequency range 0.2- 0.5 GHz. The variation of working gas pressure shows a peak radiated wave amplitude potential at 0.7 Torr.

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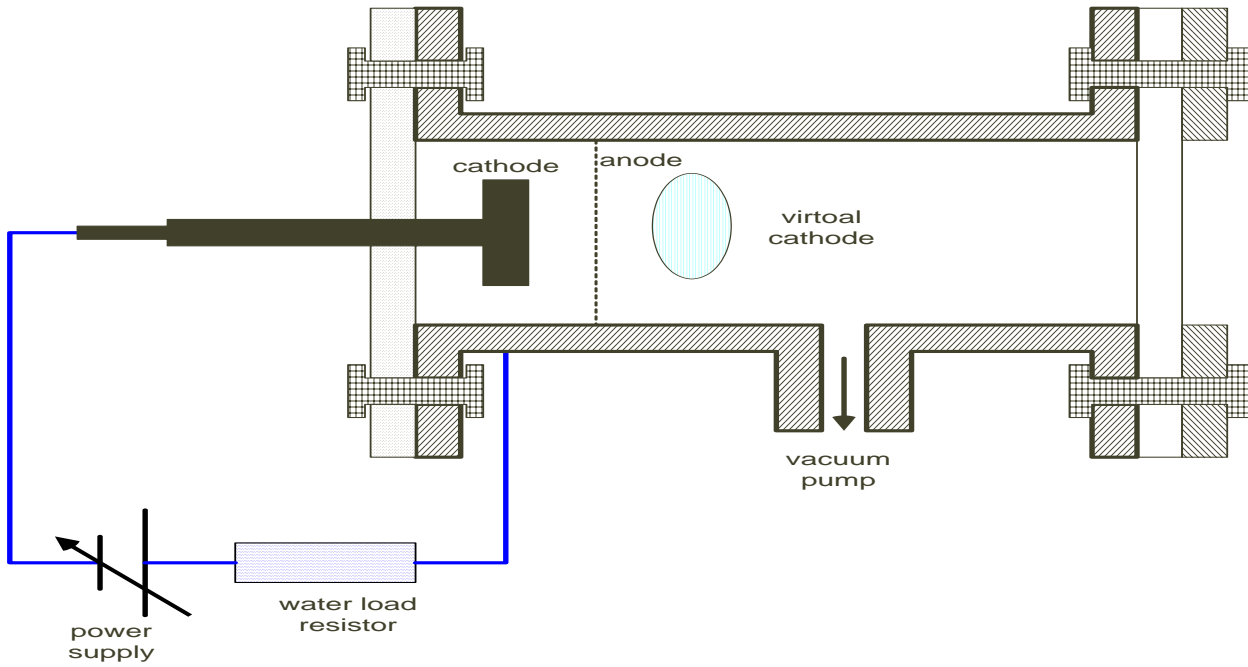


Fig. 1. Schematic diagram of vircator circuit with DC power supply

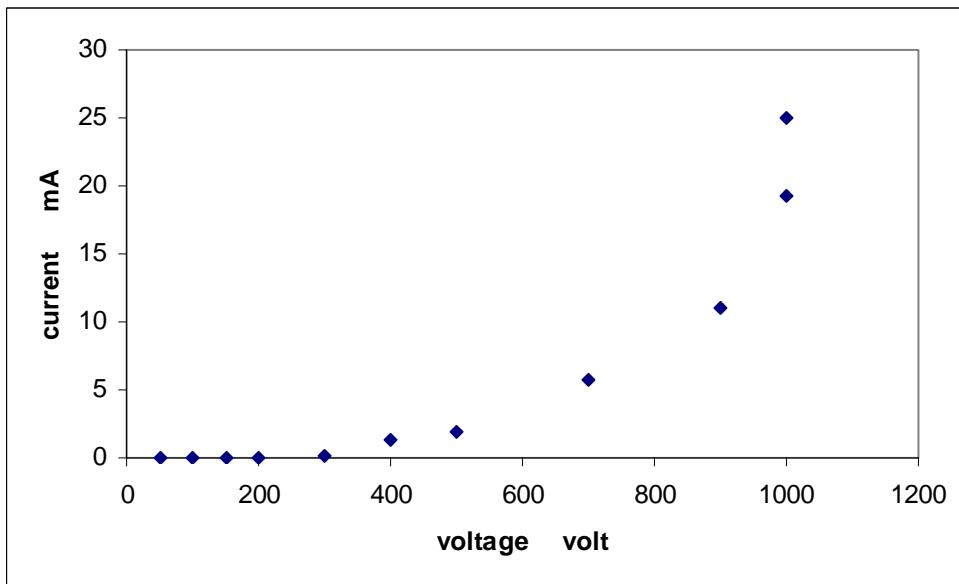


Fig. 2. I-V Characteristics of the discharge

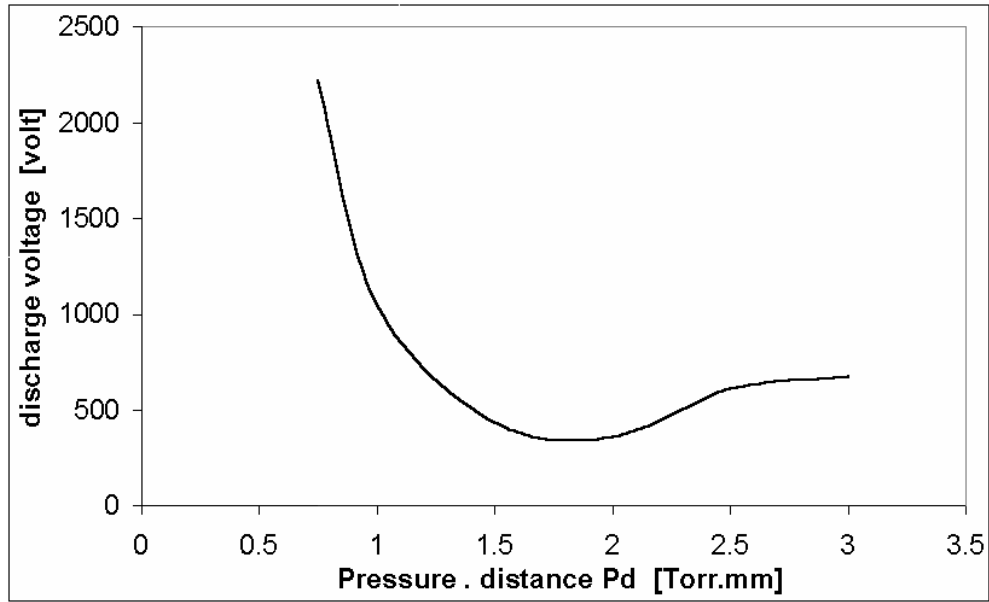


Fig. 3. Discharge voltage versus Pd

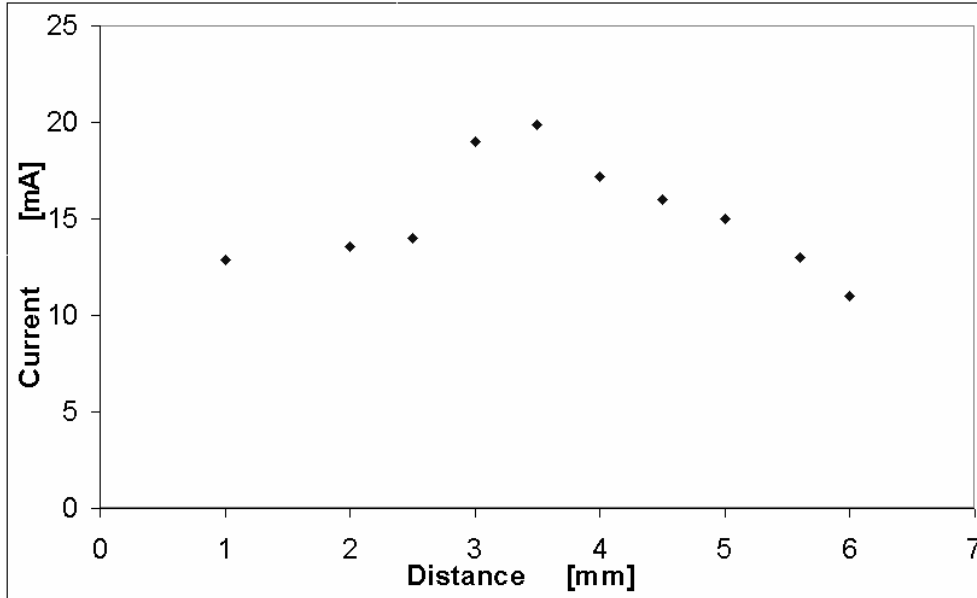


Fig. 4. Discharge electron beam current versus A-K spacing at pressure 5×10^{-1} Torr,

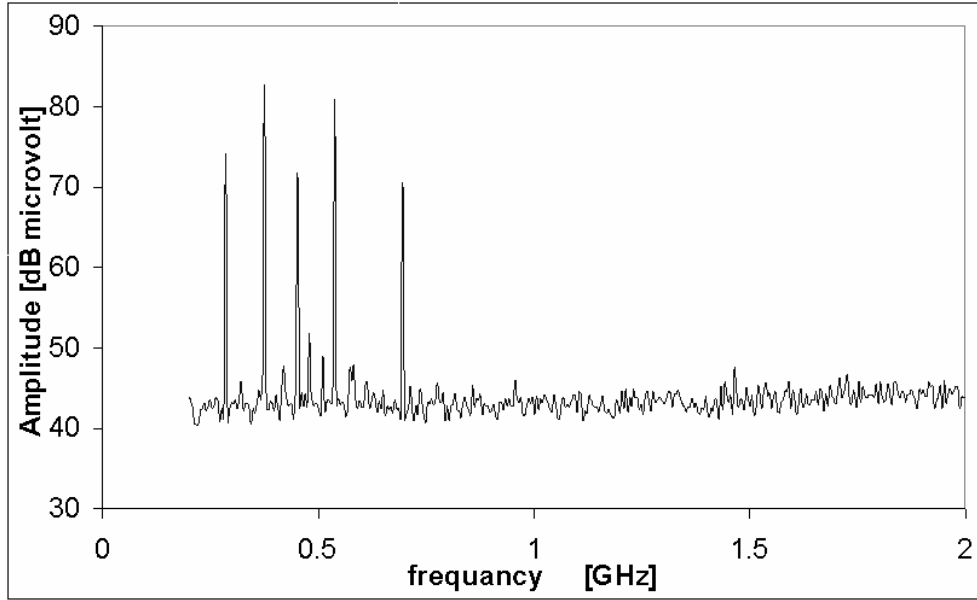


Fig. 5. The emitted microwave voltage amplitude versus frequency, by the frequency analyzer, from DC vircator operated at working gas pressure 5×10^{-1} Torr, discharge current 12.9 mA, and A-K spacing of 3.5 mm.

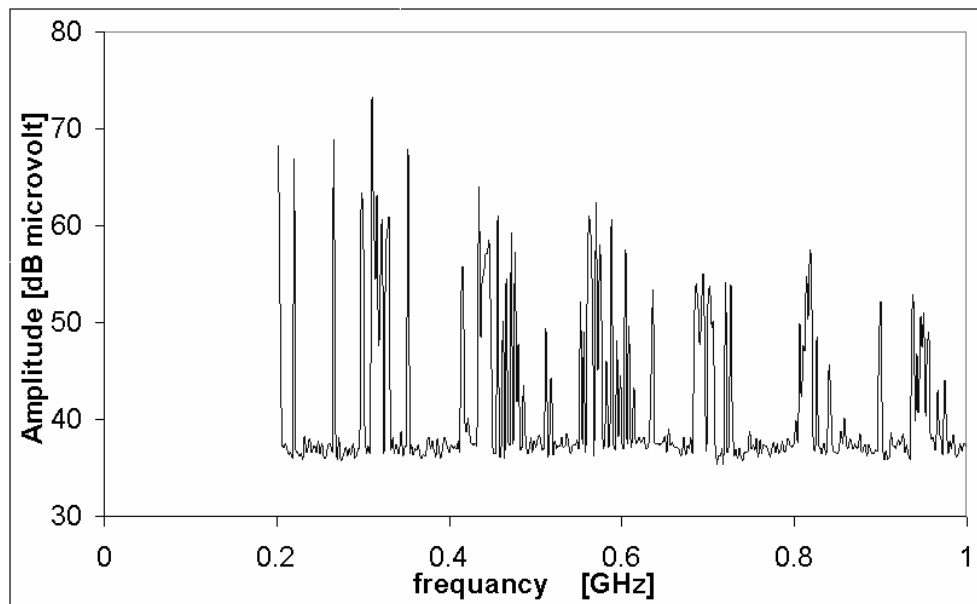


Fig. 6. The emitted microwave voltage amplitude versus frequency by the DC vircator operated at working gas pressure 3×10^{-1} Torr, discharge current 19.6 mA, and A-K spacing of 3.5 mm.

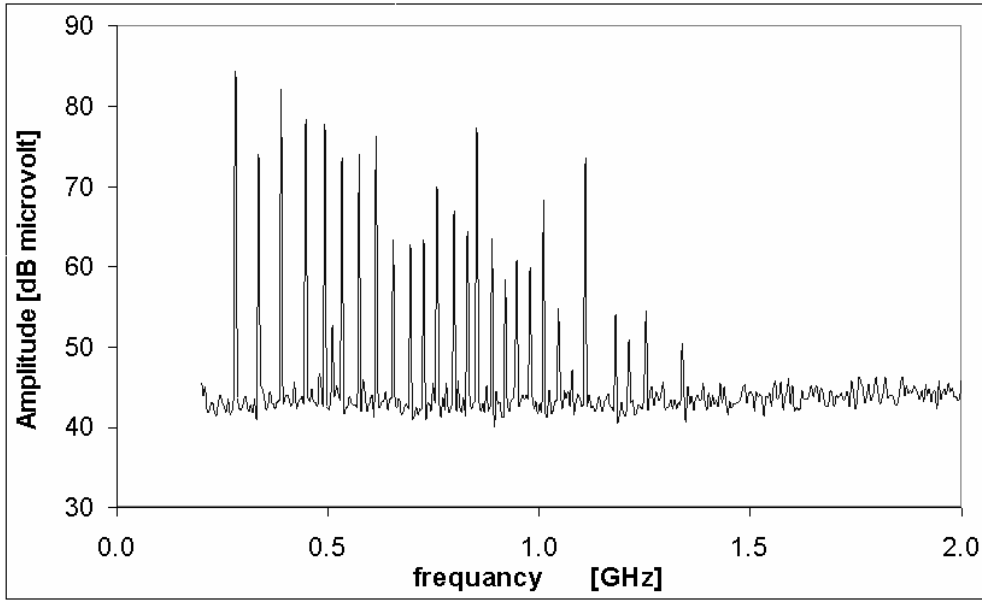


Fig. 7. The emitted microwave amplitude voltage versus frequency obtained at working gas pressures 7×10^{-1} Torr, discharge current 15.5 mA for 3.5 mm A-K spacing.

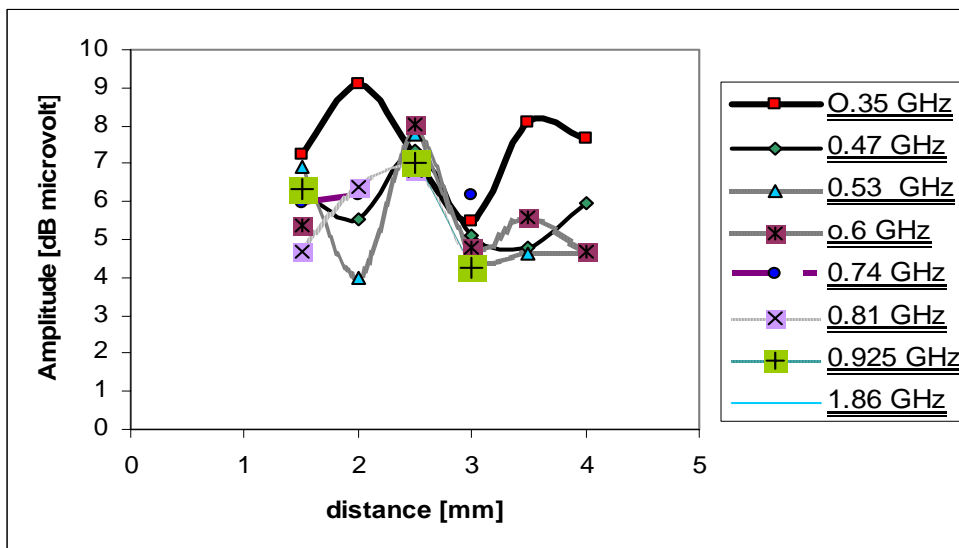


Fig. 8. Emitted wave amplitude voltage versus A-K spacing for different frequencies at $P=5 \times 10^{-1}$

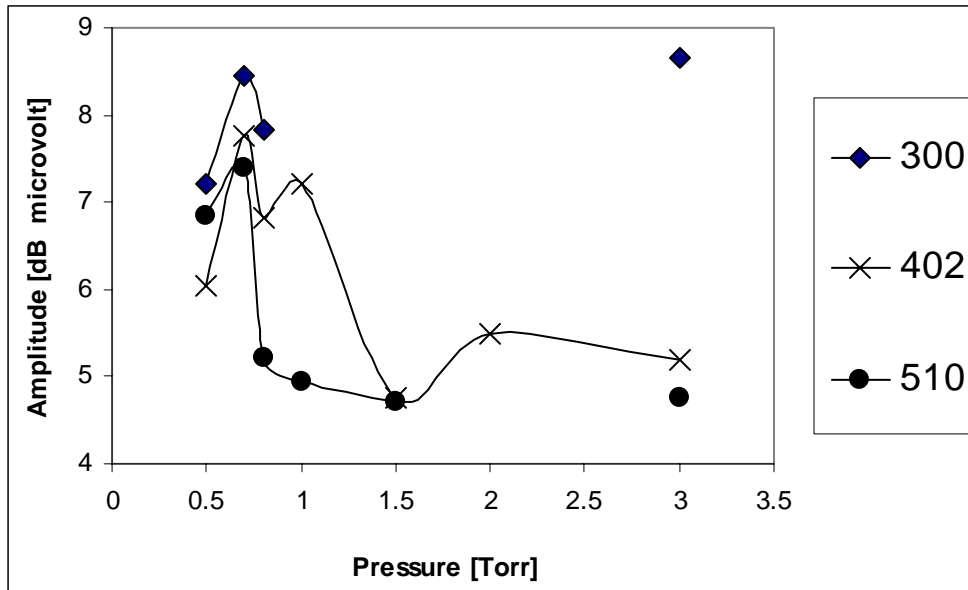


Fig. 9. Emitted wave amplitude voltage versus working gas pressure for different frequencies at d=3.5 mm.