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PLASMA PHYSICS & NUCLEAR FUSION DEPARTMENT

DESIGN AND PRELIMINARY RESULTS OF THE IMA PLASMA FOCUS EXPERIMENT

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ABSTRACT

The present paper describes the design, operation and characteristics of Aton 1MA plasma focus device, which is built in Egypt at the Plasma Physics Department, N.R.C., Atomic Energy Authority

The main parts of the system are: the coaxial electrodes of Mather type, the expansion chamber, the condenser bank of 75 KJ stored energy, the pressurized spark gap switches and Blumlein trigger system.

Measurements of the breakdown voltage between plasma focus electrodes and the discharge current, using half of the condenser bank, showed that, for $U_{ch} \cong 32$ KV, the discharge current was 0.5 MA. In the discharge current and voltage traces a sharp drop in discharge current correspondingly to a sudden rise in voltage have been observed, which characterize the focus regime.

Time structure of the X-ray emission measurements have been performed by means of scintillation detectors. By using a hydrogen gas the results showed that, the X-ray intensity is increased with increasing the hydrogen gas pressure.

Plasma sheath current density, J_z distribution in axial direction during the acceleration phase of the discharge is studied, using a miniature Rogovsky coil. The results cleared that J_z is increased with the axial distance from breech to muzzle at different hydrogen gas pressures.

INTRODUCTION

The twentieth century is faced with a challenge of finding new sources of energy in order to bridge the gap between the availabity and demand of energy. Nuclear fusion being a clean and potentially limitless source of energy offers one of the best choice.

The dense plasma focus produced in a coaxial geometry is presently the most successful plasma device for a thermonuclear fusion reactor. It has been demonstrated that nuclear fusion reaction rates in a plasma focus can be as high as 10^{19}/sec in deuterium. and 10^{21}/sec. in deuterium-tritium mixture (1-4).

Since the operation of the first plasma focus device in the early 1960's (1,2) until today, the PF has attracted scientists because of its extreme plasma properties as well as its high neutron and x-ray yield. The plasma focus devices are present in approximately 30 laboratories in at least 15 countries of the world (4,5,6)

The main purposes of the Aton plsams focus device biult in Plasma Phys. and Nuclear Fusion Dept. are:

(1) In the field of Plasma Phys., it is used for studies of states of high plasma temperature and density.

(2) Study the production of copious X-ray, which finding a different applications in fields of material studies, biological microscopy and lithegraphy.

(3) Study the neutrons yield from the plasma focus device and the possibility of used it in different applications such as: activation analysis and possible medical therapy and fusion reactor blanket studies (7).

(4) Study the energetic electron beam in plasma focus device, it may be used for excitation of atoms and molecules i.e.. for laser studies (8)

In this paper we report the design of 1MA plasma focus apparatus and the preliminary investigations carried out, mainly on the discharge current, voltage, axial plasma sheath current density distribution and X-ray emission.

Description of the System:

The Aton plasma focus apparatus has a Mather type geometry, shown schematically in figure (1), it consists essentially of cylinder brass central hollow inner electrode with a diameter of 4 cm, surrounding by outer electrode which consists of 8 parallel brass bars. The bars are uniformily distributed over a diameter of 11 cm, each of them has a length of 8 cm and a diameter of 0.8 cm. The length of the inner and outer electrode are 5.5cm and 8cm respectively. An insulator shaped ring is located between the inner and outer electrode across which the initial breakdown occurs. The coaxial electrodes system is fitted inside a stainless steel expansion chamber of 40 cm length and 38 cm inner diameter, with a thickness of 0.4 cm. The low and high vacuum gauges are connected to two adaptors fixed to the stainless steel expansion chamber. Three holes of 0.7 cm diameter are manifactured in the upper part of the expansion chamber, for a diagnostic probes. At the opposite sides of the expansion chamber, there are two slits with width of 2 cm extend from breech to 23 cm. They are closed with a glass window to detect the emission of plasma radiation through them. The apparatus is connected to a vacuum system through a 2 cm diameter hole in the back hollow part of the inner electrode, via a rubber tube with a length of 100 cm and 2 cm inner diameter. This rubber tube will protect the vacuum system from any high voltage and back currents hazards arise from the discharge system. The working gas is introduced to the volume between the coaxial electrodes from a tank via sensitive needle valve. Figure (2) shows a general view of the apparatus.

The Condenser Bank:

The condenser bank consists of two modules. Each module consists of 25 capacitors, divided in 5 rows. Each row consists of 5 low inductance condensers (45 KV, 1.5 μf each) connected in parallel. Each row is switched by a pressurized spark gap switch. The output of each module has its collector plate. The plasma focus tube is connected to the collector plates by 24 coaxial cables.

The Pressurized Spark Gap Switch:

The pressurized spark gap switch is three electrodes spark gap switch, it filled with a pressurized dry air, designed specially to stand up to 60 KV. This type of switch is called a triggatron spark gap or field distortion switch. The construction of the pressurized spark gap switch is shown in figure (3). The switch consists of a three electrodes, upper drilled electrode, lower undrilled electrode and a trigger pin electrode assembly as a third electrode. The lower electrode is screwed to the high voltage connection of the condenser bank with a special connection, for better contact. The upper electrode is screwed to the plexiglass cylinder which is used to adjust the gap between the two electrodes. The upper electrode is connected to collector plate. The trigger electrode is fixed inside the upper electrode by means of insulator, which is adjusted such that the position of trigger electrode tip lie within the surface of the drilled electrode. There are two ports in the upper drilled electrode, one is used for pressurized gas input and the other for gas purges. The lower and upper electrodes are fixed to plexiglass cylinder placed inside a cylindrical brass body. The brass body is used for current return to decrease the inductance of the switch. The brass body is connected to the earth part of the capacitor bank (capacitor body), and at the other end of collector plate. Figure (4) shows a picture for one module of the condenser bank and the pressurized spark gap switches.

The Triggering System:

The operation of a plasma focus device required a powerful discharges to be triggered sequentially at the required time.

The electrical control system for the triggering of the pressurized spark gap switches was designed so that, all switches are conducted at the same time.

The triggering mechanism is a three cascade stages:-

(a) Low voltage triggers.
(b) High voltage triggers of small switch
(c) Blumlein system.

A low voltage triggering comes from a pulse generator delivers higher pulses of 50-200 V manually or controlled repetion. This pulse is fed to high voltage pulse generator to enable triggering of the condenser bank. This high voltage triggering unit was a thyratron tube with an additional circuit to trigger it manually. A pulse of 500 V is fed to the thyratron grid. The output pulse of high voltage triggering is fed a trigger electrode of spark gap switch, which is used to trigger a Blumlein.

Blumlein Triggering Pulse:

The pressurized spark gap switch of a condenser bank is triggered by a Blumlein generator via the three electrode spark gap switch, shown in figure (5). This switch is a field distortion switch. The H.V. electrode of it is charged up in our case to 35 KV.

The Blumlein cables are charged to a positive potential 35 KV. (9). The output of the Blumlein cables are connected to the trigger electrode of the pressurized spark gap switches via the triggering cables, as shown in figure (6). When the three electrode spark gap switch is triggered, the two units of Blumlein cables are charged up to 35 KV. Then as a result of the discharge between the cables which are connected to upper electrode of spark gap switch and the others during a second half cycle of the discharge. Hence the output triggering pulse is nearly double the cables charging voltage i.e. 70 KV.

Safety System:

The experiment is divided into three parts:

(1) Low voltage system located in the control rocks. This system consists of low voltage trigger pulse system, charging monitor meters, air pressure control meter, a pressurized air filter and a compressor of air device.

(2) The high voltage experimental area contains the 1 MA plasma focus chamber, condenser bank, pressurized spark gap switches, high voltage pulse systems, high voltage power supplies, high voltage Blumlein cables and vacuum system.

(3) Around the experimental area, there exists an earthed metalic mesh fence and it has two doors. One is used for normal working entrance and the second for the equipments. These doors are closed with a castle lock special key which can not be removed unless the door is closed. The castle lock key is used also to energise the H.V. supplies.

Inside the experimental area, there are four a fixed dump switches. These switches are connected with the control board and dump the charges immediately upon pressing. Dump switches are lifted up automatically when the power supplies are energised and they go down and dump the charges when the power supplies mains control board are switched off.

One earth stick system has been manifactured and fixed on the wall, at a position, that it can reaches the high voltage connections. In order to be sure that, the condenser bank has no any charge on it, the earth stick conductor part must be placed at the high voltage leads of the condenser bank during the maintenance.

The earth of each equipment has been brought to one main point by a copper strips. The main earth point of the system is connected to an earth well filled with water, salt and fine coal. This well is checked periodically to detect the constancy of the water level.

OPERATION PROCEDURE

The sequence of operation of the 1MA plasma focus device are:

(1) Evacuate the apparatus and adjust the gas flow to working condition.

(2) Closed the doors of the experiment and switch-on the experiment mains by the castle key G.

(3) Switch-on the low voltage pulse system and thyratron filament and wait for five minutes.

(4) Switch-on the compressor and adjust the air gap pressure.

(5) Press on the control switch of each dumps respectively from the main control unit, then they energised . After this, all dumps are lifted up and the system is isolated.

(6) Switch on the high voltage power supplies.

(7) Apply the high voltage to the main Blumlein cables

(8) Make sure that the trigger pulse system is operated, and then charge the capacitors.

(9) Apply the trigger pulses from a Blumlein cables to a pressurized spark gap switches to discharge the condenser bank.

(10) A discharge current passes to coaxial electrodes of a plasma focus device, through 24 coaxial cables. The total discharge current passes through inner electrode of coaxial electrodes, the outer electrode is used as a current return and is connected to the earth.

In the coaxial plasma focus device, the following five phases of discharge occur in its dynamics:

(a) The inverse pinch along the surface of the insulator at the beginning of the discharge.

(b) The rundown of plasma sheath current as a result of the $J_r \times B_\theta$ force towards the coaxial electrodes muzzle where J_r is the radial plasma sheath current and B_θ is azimuthal magnetic field.

(c) The collapse of the plasma sheath at the centre of muzzle.

(d) The formation of plasma focus.

(e) The diffusion and cooling of the plasma.

EXPERIMENTAL RESULTS AND DISCUSSION

The plasma focus apparatus is energised starting by one module of the capacitor bank, with 4.2 kJ for 15 KV charging voltage, then with storage energy of $\simeq$ 10.2 kJ for 32 KV charging voltage. The apparatus is operated to filling pressure of (0.4, 1.3 and 3.2 Torr) hydrogen gas. A Rogovsky coil having 450 turns of 0.8 cm diameter has been placed around the charging cables to measure the total discharge current. The voltage across the electrode terminals at the breech end of the coaxial electrodes is measured by a resistive voltage divider of 1 : 100.

The discharge current and voltage wave forms are shown in figure (7A), for U_{ch} 15 KV, this figure cleared that at $t \cong 3\ \mu s$, there is a sudden rise in voltage and a sharp drop in current. This indicates the presence of the plasma focus regime

At $U_{ch} \approx 15$ KV and 32 KV, the condenser bank delivers to a coaxial electrodes plasma focus device a current of 0.22 MA and 0.5 MA respectively. Figure (7B) shows a discharge current and voltage wave forms are smooth without any dip or spike, this for non-focusing shot ($U_{ch} \approx 10$ KV). Figure (8) shows the discharge current signal, and the presence of plasma focus for $U_{ch} \approx 32$ KV.

The X-ray emission is detected by the X-ray detector (plastic scientillator, light guide and photomultiplier system). This detector is located at 10 cm from the coaxial electrodes muzzle surface. Figure (9A,B) shows the discharge current signal and the time structure of the X-ray emission, two individual X-ray pulses, are recognized. Each pulse represents the radiation from an individual spot, for $U_{ch} \approx 15$ KV and there exist one pulse for $U_{ch} \approx 10$ KV. The results of X-ray intensity measurements as a function of hydrogen gas pressures are shown in figure (10).

A miniature Rogovsky coil of 20 turns, internal and external diameters are 2 mm and 5.5 mm respectively, is used to measure the axial plasma sheath current density at different positions along the coaxial electrodes. Figure (11) shows a typical axial plasma sheath current signal together with discharge current waveform. The dependence of the axial plasma sheath current density on the hydrogen gas pressure at different distances along the coaxial electrodes is shown in figure (12).

CONCLUSION

The design, construction of 1MA plasma focus apparatus and the modification of the switches for the one module condenser bank of 37.5 kJ by using a pressurized spark gap switches with very low noises had been carried out. Experimental results of discharge current and voltage showed that, a sharp drop in discharge current signal occurred at the same discharge time with a sharp rise in breakdown voltage signal (the plasma focus position), for charging voltage. $U_{ch} \cong$ 15KV, the maximum discharge current $\cong$0.22 MA. For $U_{ch} \cong$ 32 KV, the discharge current signal cleared that the plasma focus occurred at approximately at the beginning of discharge current ($I_{max} \cong$ 0.5 MA). X-ray emission measurements cleared, an X-ray pulse is appeared approximately at the same discharge time for U_{ch} 10 KV and 15 KV, this may emitted from the axial run-away plasma inside the expansion chamber. A second X-ray pulse is appeared from $U_{ch} \cong$ 15 KV approximately at focusing time. The X-ray emission intensity is increased by increasing the charging voltage and the hydrogen gas pressure. The axial plasma sheath current density, J_z measurements along the coaxial electodes illustrated that J_z is increased with the distance from breech to muzzle and with increasing the hydrogen gas pressure.

The second module of the condenser bank with another five pressurized spark gap switches is under construction, and it will be connected to the first module of condenser bank . Theoretical calculations for both modules and the experimental results for the first module, showed that, the two modules will deliver 1MA discharge current at charging voltage of 32 KV.

The discharge current can be increased up to 2 MA for charging voltage of 45 KV, but in order to increase the life time of the capacitors it is recommended not to exceed 1.5 MA.

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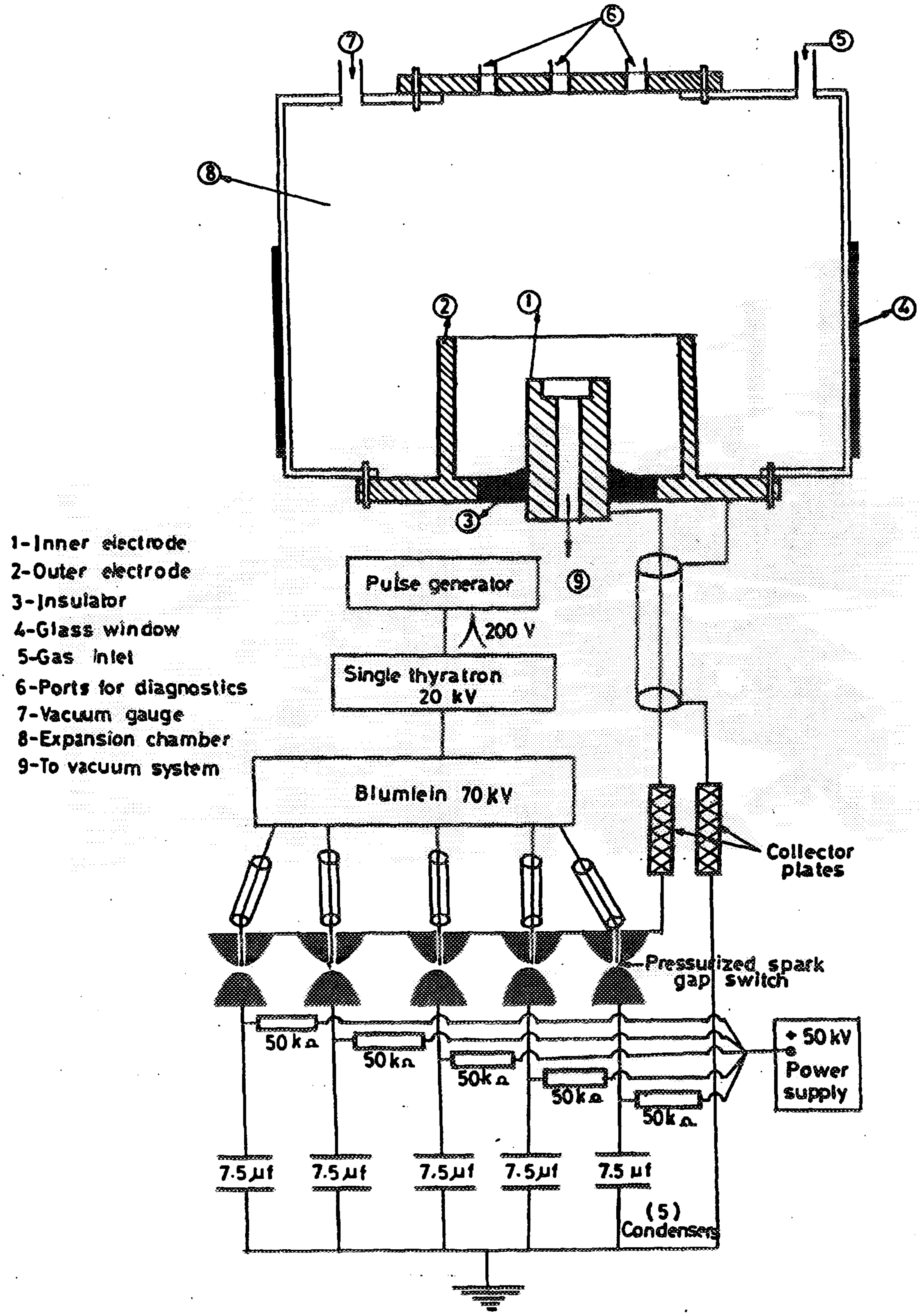


Fig.(1'): Cross section of the plasma focus apparatus.

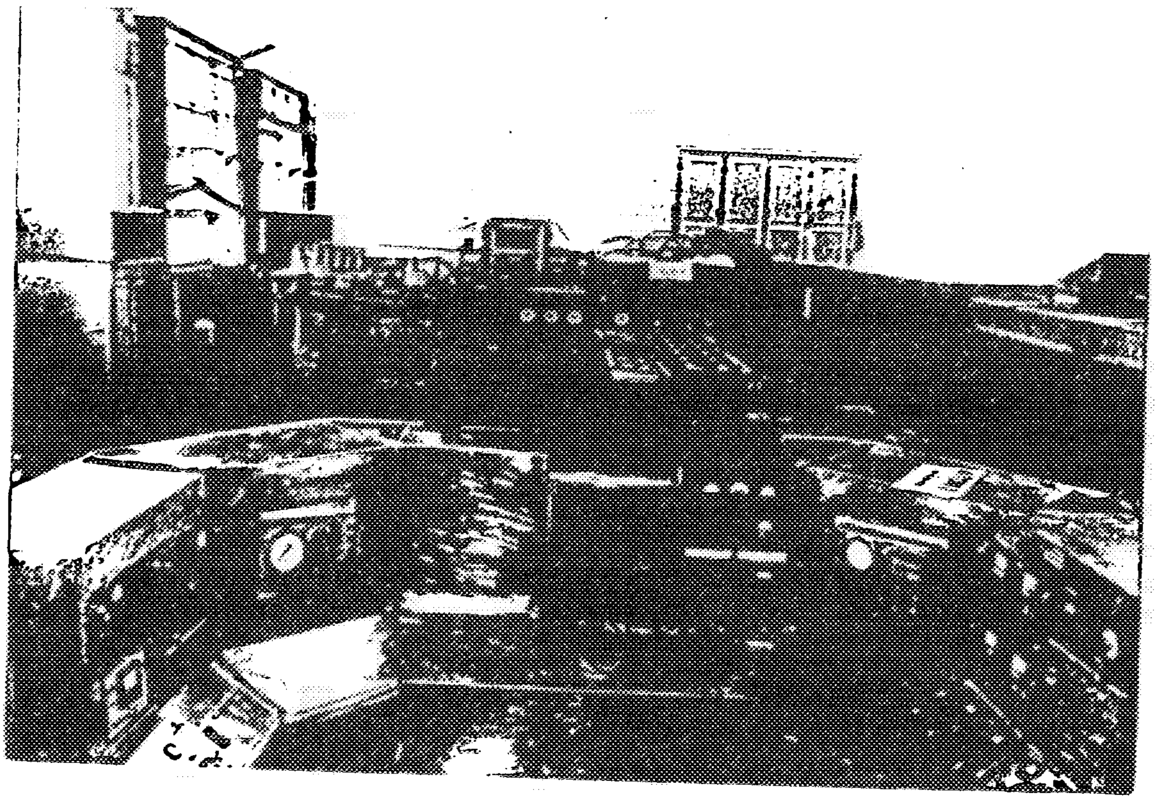


Fig.(2) General view of the apparatus

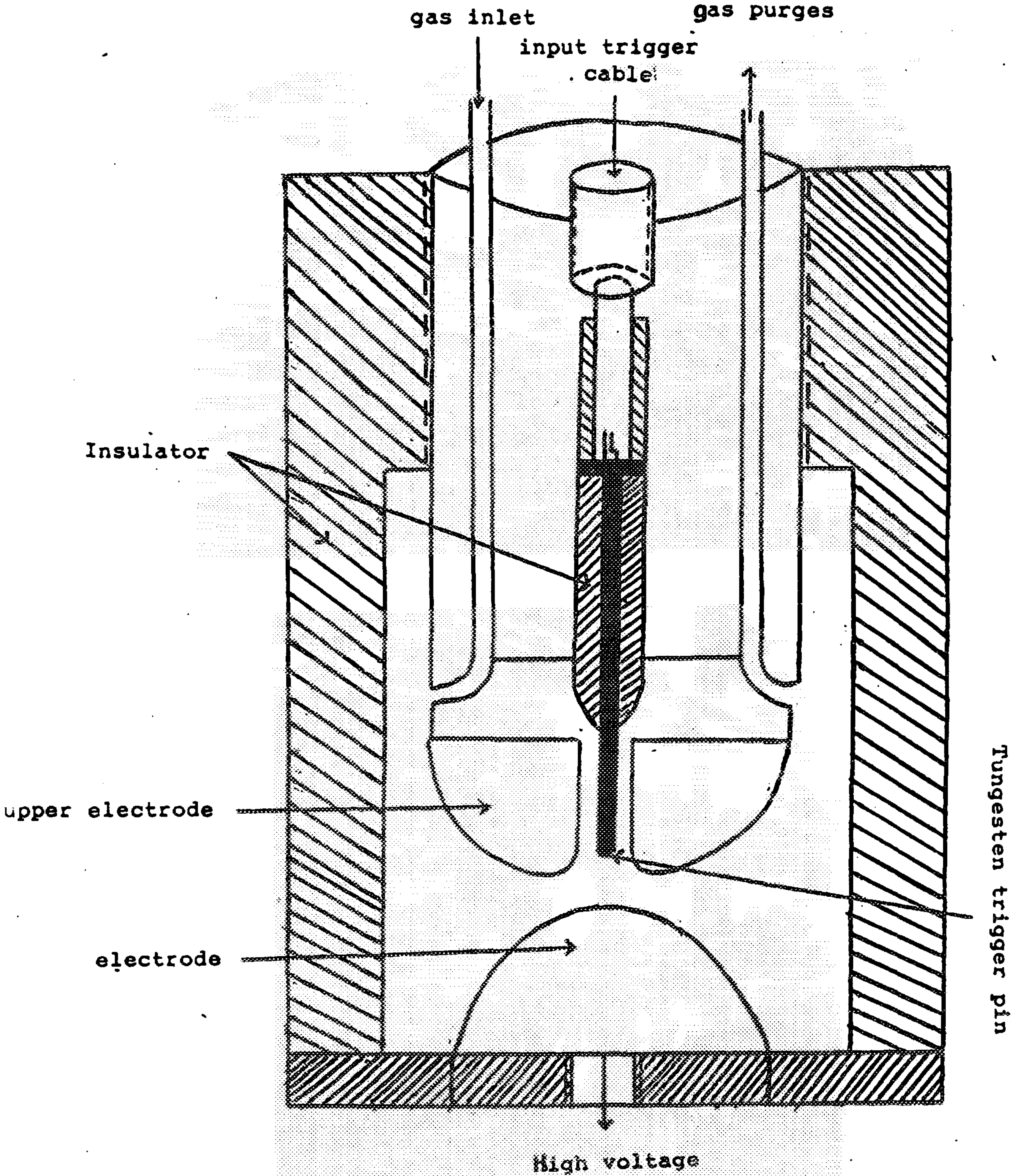
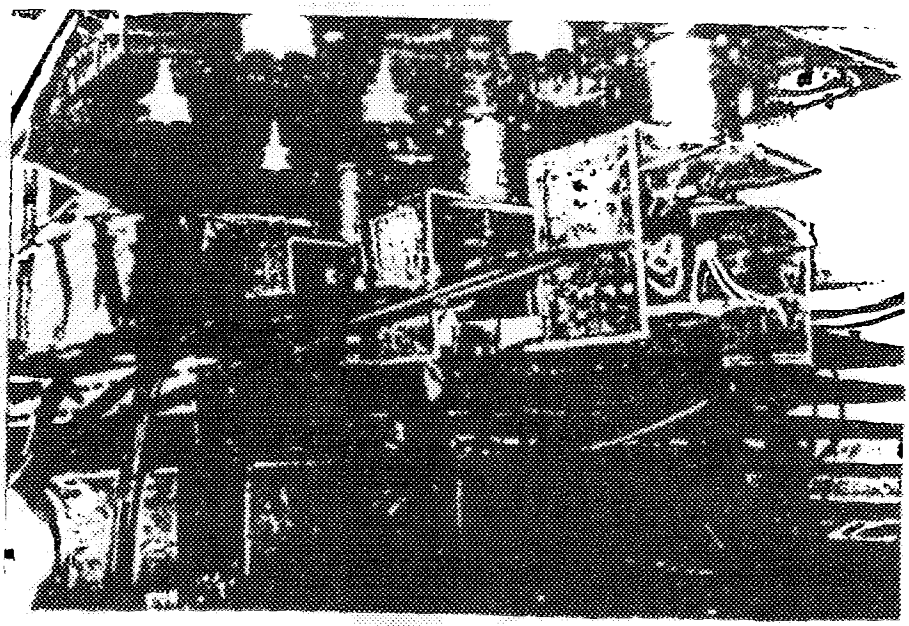
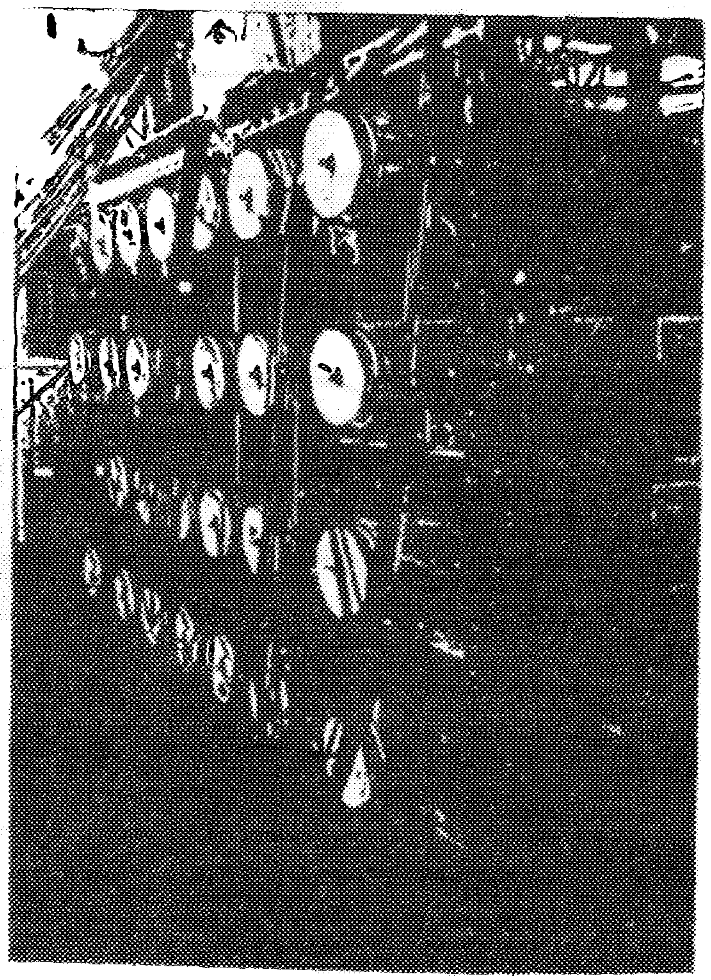


Fig. (3) : Pressurized spark gap switch.



the pressurized spark gap switches



the condenser bank

Fig.(4) A picture for one module of the condenser bank and the pressurized spark gap switches

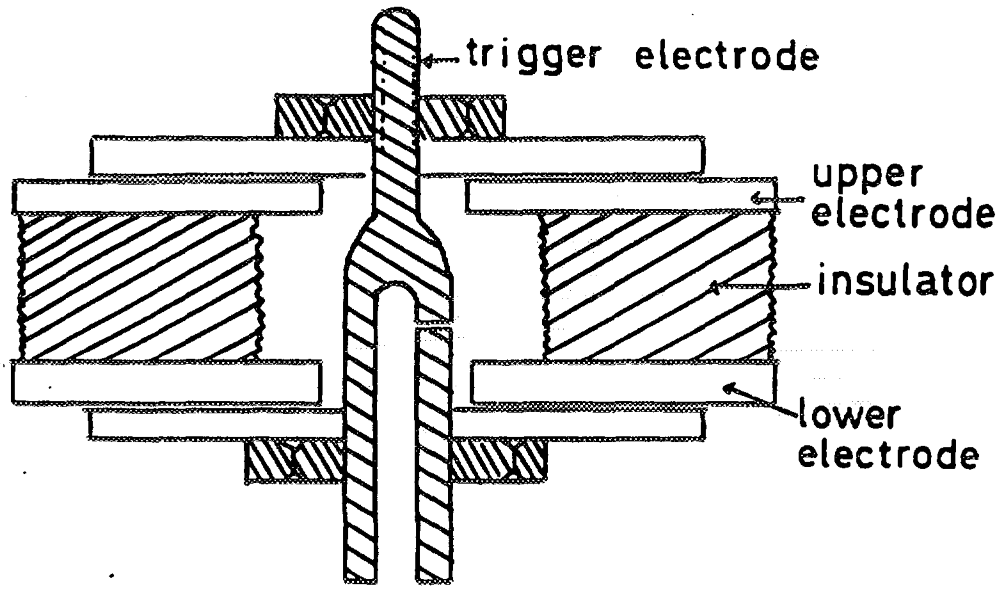


Fig. (5) Blumlein spark gap switch

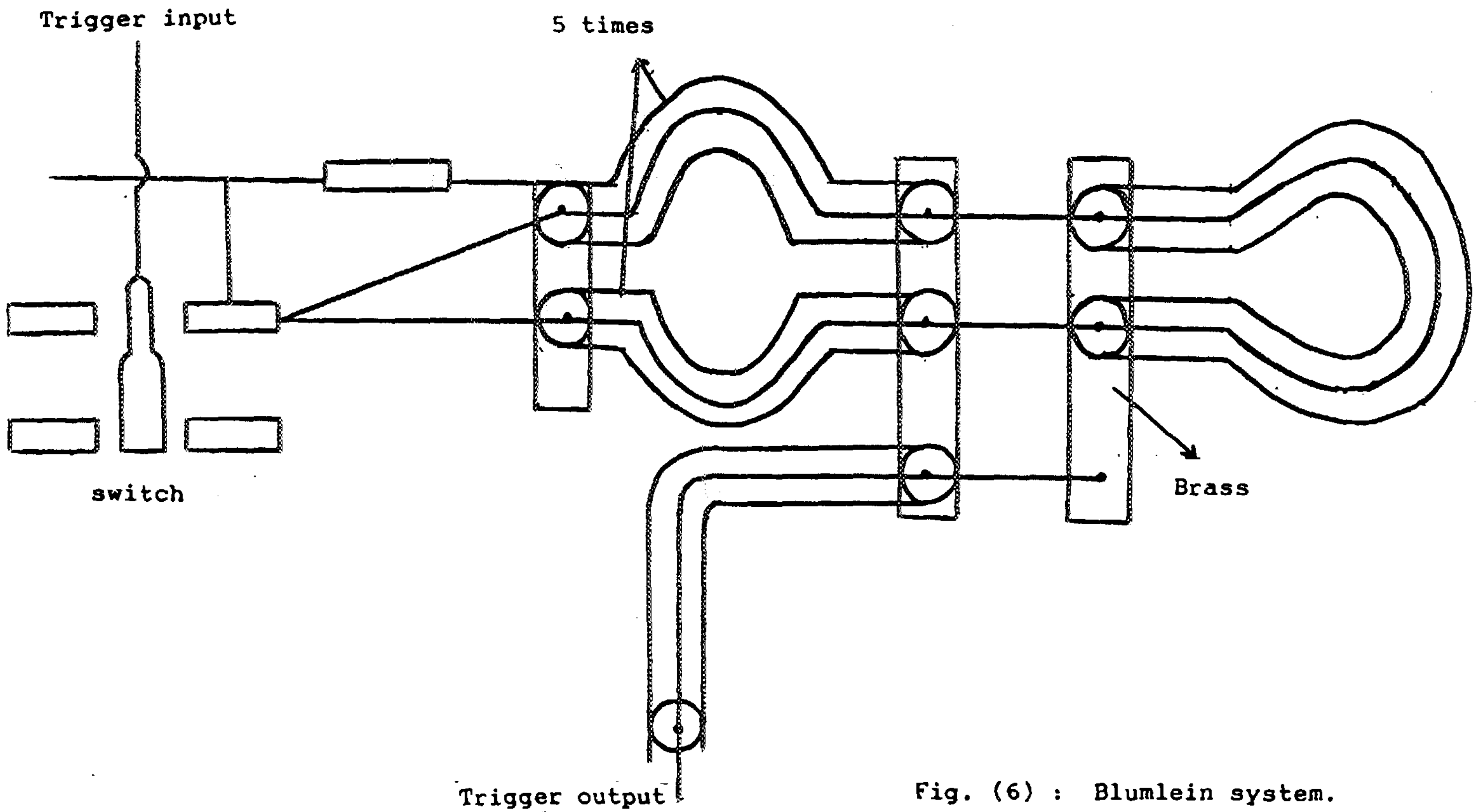


Fig. (6) : Blumlein system.

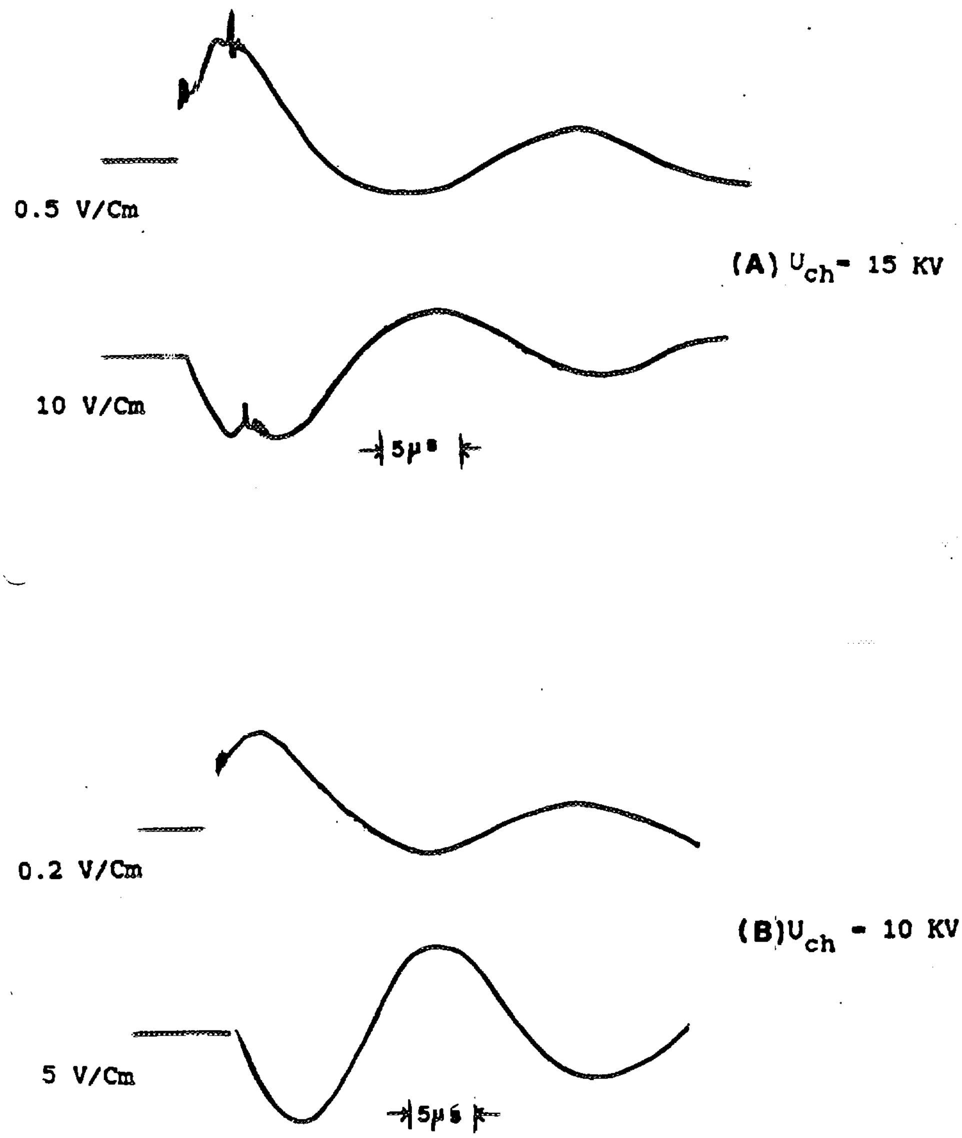


Fig.(7A,B): Oscillograms of breakdown voltage pulse (upper trace) and discharge current pulse (lower trace) for (A) U_{ch} = 15 KV and for (B)U_{ch} = 10 KV and P = 1.2 x 10^{-1} Torr.

Fig.(8): Oscillogram of discharge current pulse for U_{ch} = 32 KV.

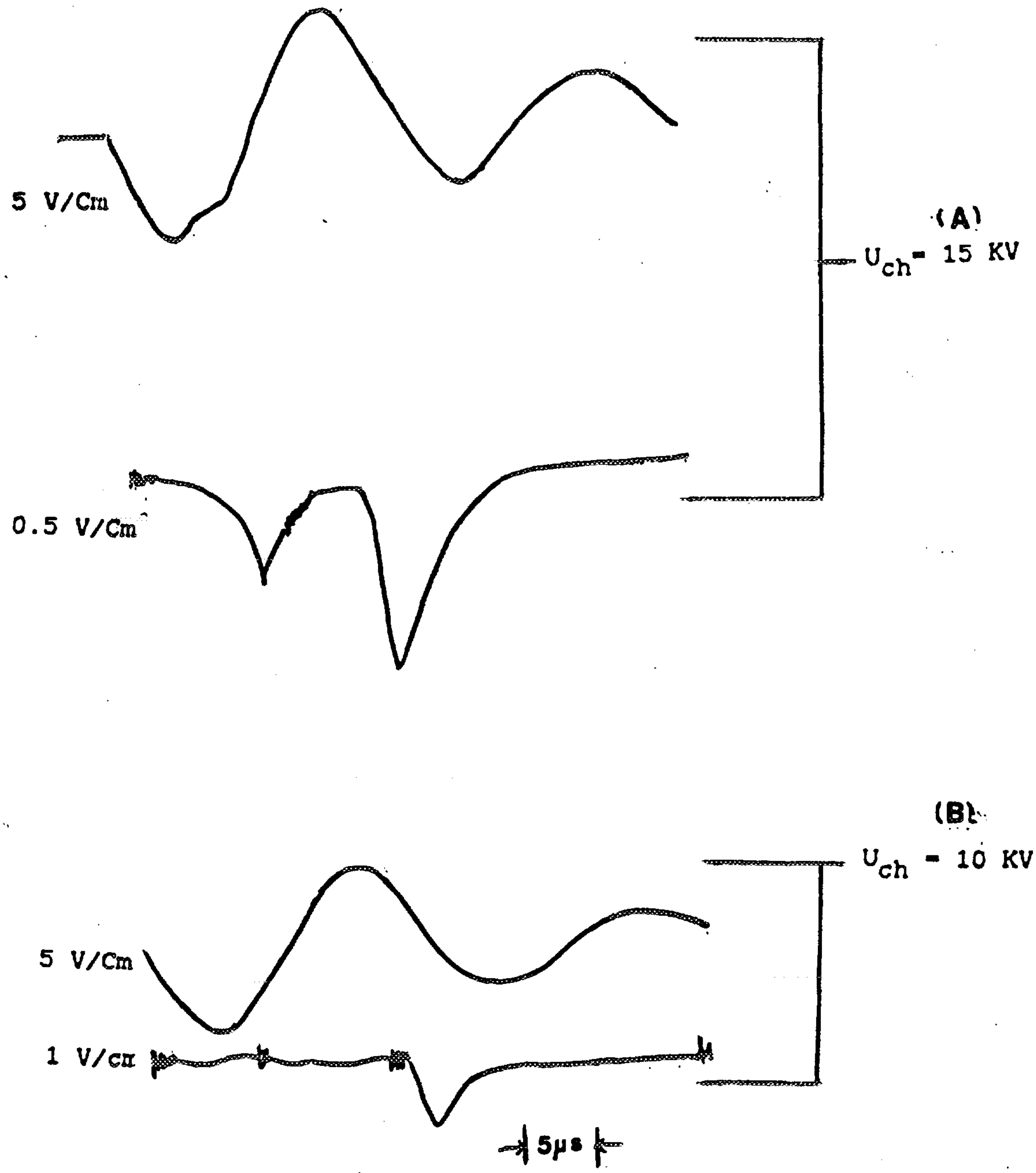


Fig.(9): Oscillograms of discharge current pulse (upper trace) and time structure of x-ray pulse (lower trace), for (A) U_{ch}=15KV and for (B)U_{ch} = 10 KV. P = 1.3 Torr.

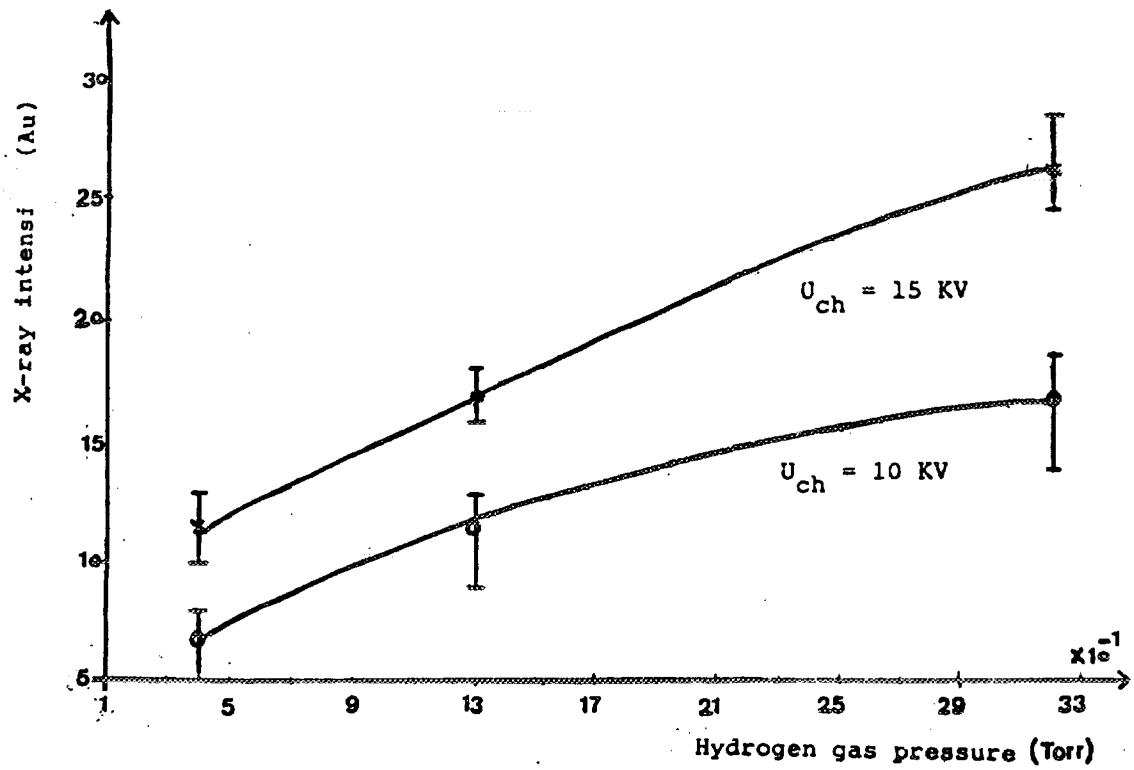


Fig. (10): The relation between the x-ray intensity and the hydrogen gas pressure.

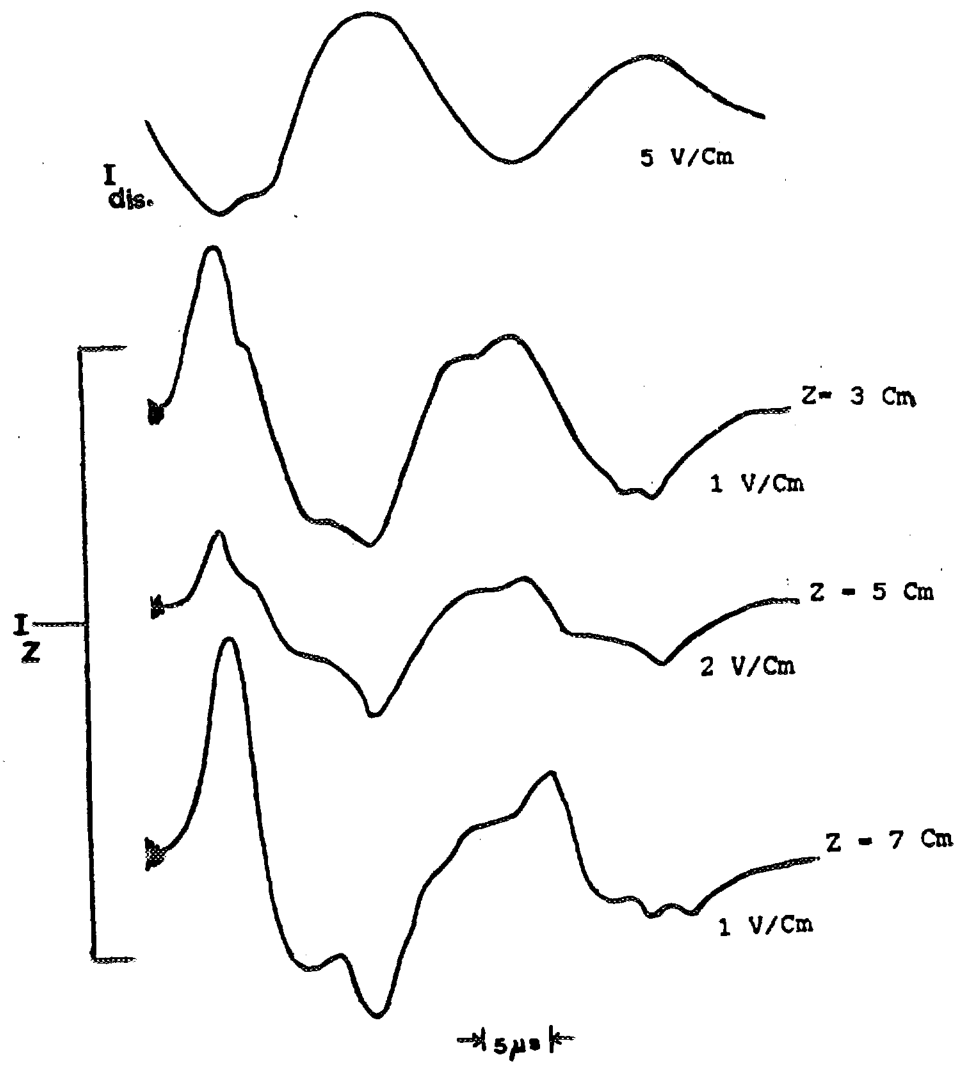


Fig.(11): Oscillogram of discharge current signal and axial plasma sheath current signals for U_{ch} = 15 KV and P = 3.2 Torr.

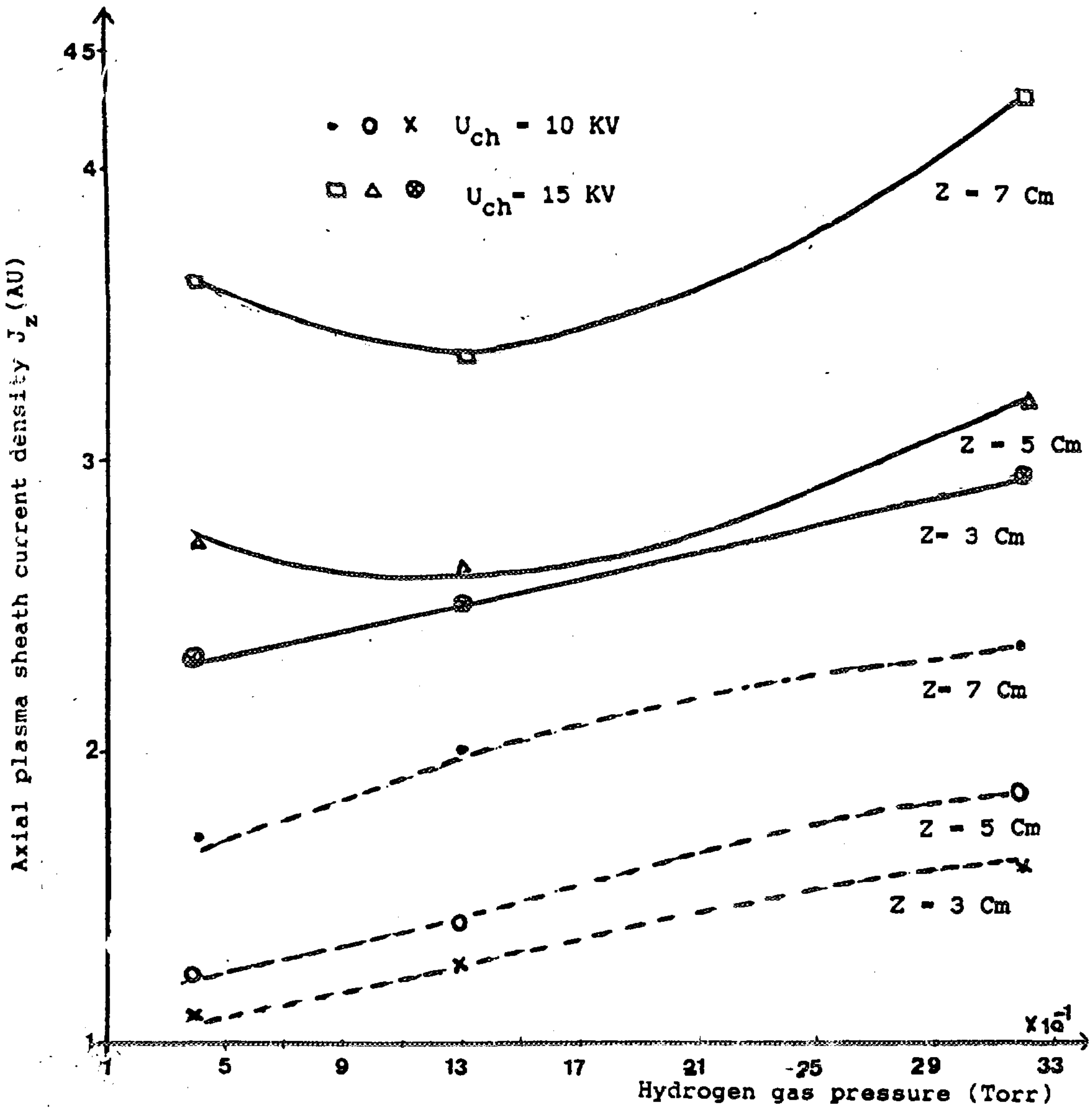


Fig.(12): The relation between the axial plasma sheath current density and the hydrogen gas pressure.