P.R.L.

TECHNICAL NOTE

TN-~~81-04~~ 81-23

SYSTEM OPERATION FOR PLASMA-NEUTRAL GAS INTERACTION EXPERIMENT

By

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April, 1981

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ABSTRACT.

This report describes a system to discharge sequentially four stored condenser banks. These are used for producing a pulsed magnetic field, for opening two electromagnetic gas valves and producing a plasma discharge in the coaxial plasma gun deployed in experimental system to study the interaction between a magnetised plasma and a neutral gas. The discharges are initiated by firing spark gaps through thyratron switches which, in turn, are operated by trigger signals. The condenser banks are discharged in a sequence pre-determined by the experimental requirements.

1. INTRODUCTION.

A schematic of the experiment on an interaction between magnetized moving plasma stream and a stationary gas cloud set up at the Physical Research Laboratory is shown in fig. 1. It basically consists of a plasma gun which produces high speed plasma stream and an interaction region wherein the plasma stream penetrates a stationary gas cloud. The plasma source and the interaction region are connected by a drift tube which is provided with longitudinal magnetic field to reduce the losses to the walls due to diffusion. What is to be noted is that this experiment uses four condenser banks. The energy stored in these banks is utilized to open two fast electromagnetic valves, one provided at the interaction region and another one to admit gas into the plasma gun to set up longitudinal magnetic field in the drift tube and to provide energy for discharge of the gas and its subsequent acceleration in the plasma gun. Further these banks are to be discharged sequentially. The requirements are as follows:

(1) For opening the electromagnetic gas valve situated at interaction region, a fast ($\sim$25 μsec) high current (100 kA) pulse is to be passed through the field coils of electromagnetic valve. A similar current pulse is needed for opening another electromagnetic valve situated at plasma gun to inject a gas cloud but with an adjustable delay.

(2) A slow (~3 msec) high current (125 A) pulse is to be generated and passed through the 40 cm long 16 cm diameter solenoid coils for producing a uniform axial magnetic field of 5 kG in the drift space to guide the plasma stream from the muzzle of gun to the interaction region. The large pulse time ensures a slow time variation of magnetic field while the plasma stream passes through drift space and interaction region.

(3) These three discharges have to be sequentially obtained with definite controllable delays between them as shown in fig. 2. This scheme of discharging different capacitor banks is adopted so as to ensure that plasma moves through the drift space when the magnetic field is at its peak value and that the plasma stream meets neutral gas cloud in the interaction region at the required time of gas evolution.

(4) The bank connected to the plasma gun is discharged by injection of the gas through the valve.

This report describes condenser banks, thyratron switches for transfer of energy and sequencing of the different operations from production of plasma stream to its meeting with the gas cloud of pre-specified density.

2. CONDENSER BANKS.

A basic circuit of a condenser bank is shown in fig.3. It consists of a stack of condensers charged by a power supply. The energy is transferred to the field coils/magnetic field coils by using a low inductance spark gap.

Table 1 lists the designed parameters of different capacitor banks. It can be seen that requirements vary from 100 kA to 125 A in current and 25 μsec to 3 msec on the pulse width of discharge currents. These requirements are met by optimising impedances of capacitor banks and peak charging voltages. The transfer of energy is executed in the following way in all condenser banks except the one used with the plasma gun. The condenser bank is charged initially to a specified value of voltage. The spark gap is fired by a high voltage pulse (6 kV, 5 μsec) derived from a thyratron. The discharge path is provided through field coils/solenoids (for obtaining magnetic fields). Note that the condenser bank connected to the plasma gun is not connected to any spark gap. It is discharged when sufficient gas pressure builds up inside the coaxial gun after the electromagnetic valve is opened to admit the gas.

3. TRIGGERING SYSTEM.

The discharge of various condenser banks are initiated with the help of high current spark gaps, which in turn, are fired by a triggering unit. The triggering unit consists of

(a) master trigger, (b) pulse generators, (c) SCR trigger generators and (d) thyratron circuit.

3.1 Master trigger.

Master trigger unit is one which gives a monoshot pulse on the mechanical pressing of a push button, which triggers the whole sequence of discharges. The circuit diagram for obtaining this pulse is shown in dotted section of fig. 4.

3.2 Pulse generators.

The master trigger pulse generates six different pulses which are used for triggering SCRs and for locking SCRs till the triggering time is reached. The circuit is shown in fig. 4. Fig. 5 explains the nature of these pulses and their sequence.

3.3 SCR trigger generators.

The three triggering pulses derived from the circuit shown in fig.5 are fed to three SCRs in parallel which generate correspondingly three trigger pulses for thyratrons. The circuit diagram is shown in fig.6. During the triggering of first thyratron, the other two thyratrons normally get triggered owing to stray pulses. To avoid this, the capacitances C' and C" are not allowed to get charged by keeping the transistors Tr' and Tr" conducting till the required time of triggering. This is achieved with the help of long pulses c & d indicated in fig.5. A good shielding further reduces any cross-talk between different triggering units. The typical output pulse of an SCR is of 2 μsec duration and the peak voltage is 175-300 volts. The maximum current that can be drawn is 1 amp.

3.4 Thyratron trigger circuit.

The trigger pulse output at SCR is of low energy and cannot directly be used to activate the spark gap situated in discharge circuits. We have used thyratron switches to fire the spark gaps. The minimum voltage pulse needed to trigger the thyratron used is 175 volts and minimum pulse width is 2 μsec. This is easily matched by the SCR output. A typical thyratron circuit is shown in fig.7. The output pulse is obtained across a resistor. Its peak voltage can be varied from 0.3 to 6 kV. The pulse width is about 5 μsec. The maximum $i\tau$ value allowed for the thyratron used in our triggering unit is 0.1 A sec.

4. SYNCHRONISATION.

The delay between the discharges of three condenser banks can be controlled externally by adjusting the triggering time of three SCRs. This is done by adjusting the delays in the outputs of pulse generator. The observed plasma discharge current, valve opening pulse, and magnetic field current pulse is shown in fig. 8. Note that plasma is produced when the magnetic field is maximum. It is to be mentioned that difference between the two valve opening current signals corresponds to the sum of generation time of plasma and transit time in our set-up for the plasma stream to move from coaxial plasma gun to interaction region.

5. CONCLUDING REMARKS.

A block diagram of the whole set-up is shown in fig.9. This set-up enables us to study the interaction between moving plasma and neutral gas clouds of densities in a wide range (10^{17}-$10^{21} m^{-3}$). In our set-up, the varying density of gas cloud is obtained by varying the condenser bank voltages in the discharge circuit for valve opening. The finer changes in densities are obtained by triggering the second and third SCRs with proper delays so that the plasma stream meets the neutral gas cloud at the required density while the injected gas cloud evolves in time. The experiment has become operational since 1977 and is yielding excellent data on various aspects of the plasma-neutral gas interaction.

Table 1.

Relevant parameters of various discharge circuits.

Parameter	Guide mag. field	Gas valve for feeding gas to plasma gun.	Gas valve for injecting gas cloud at interaction region.	Coaxial Plasma gun.
Bank capacitance	20 μfd	14 μfd.	14 μfd	56 μfd.
Bank voltage	5 kV	10–12 kV	8–12 kV	6–10 kV.
Load	Solenoid coil.	field coil for opening electromagnetic valve.	field coil for opening electromagnetic valve	Plasma gun discharge
Inductance	16 mH	1 μH	1 μH	0.1–5 μH
Capacitance	–	–	–	50 nfd
Line inductance	negligible	negligible	negligible	0.2 μH.
Pulse period	2 msec	25 μsec	25 μsec	26 μsec
Peak discharge current	100–125 Amp	100 kA	100 kA	0.25– 5 kA.

Figure Captions.

1. A Schematic of the experiment.
2. The required triggering ranges - (a) trigger pulse for guide magnetic field (b) trigger pulse for opening electromagnetic gas valve to feed gas to coaxial plasma gun. The triggering time is adjusted to ensure that plasma stream moves in the drift space when guide magnetic field is maximum. (c) Trigger pulse for opening electromagnetic gas valve to inject a gas cloud in the interaction region. The indicated triggering range enables plasma stream to meet the gas cloud at various densities.
3. A typical discharge circuit fired by a spark gap.
4. Circuit diagram for producing monitor and delayed trigger pulses.
5. Sequence of various pulses obtained from circuit shown in fig. 4.
6. Circuit for triggering SCRs.
7. A typical circuit for triggering thyratron unit.
8. Oscilloscope picture showing the synchronisation of current pulses which open the gas valves with the half-sine guide magnetic field.
9. Block diagram of the experimental set-up.

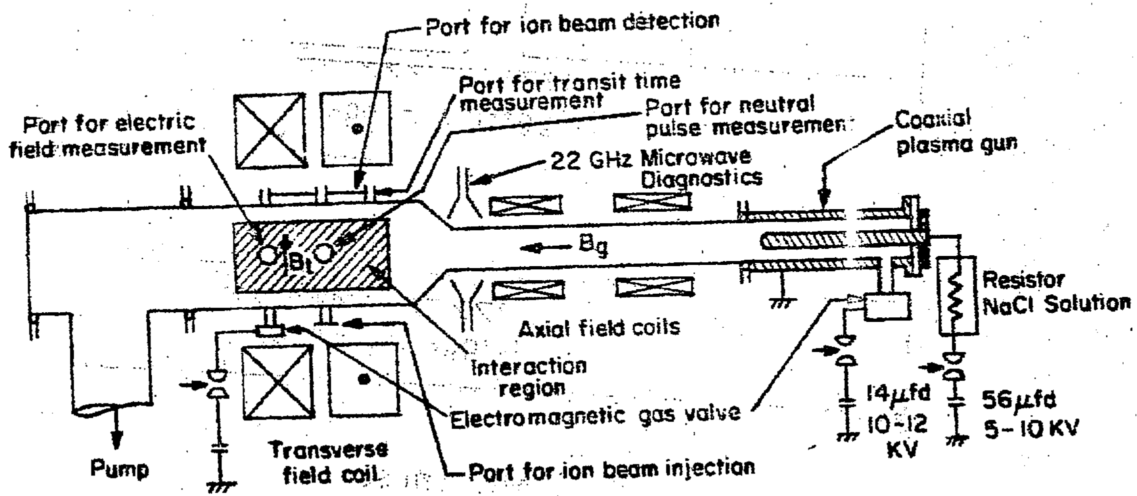

Port for ion beam detection
Port for transit time measurement
Port for neutral pulse measuremen
Coaxial plasma gun
Port for electric field measurement
22 GHz Microwave Diagnostics
B_g
B_t
Resistor NaCl Solution
Axial field coils
Interaction region
Electromagnetic gas valve
14μfd 10-12 KV
56μfd 5-10 KV
Pump
Transverse field coil
Port for ion beam injection

Figure 1

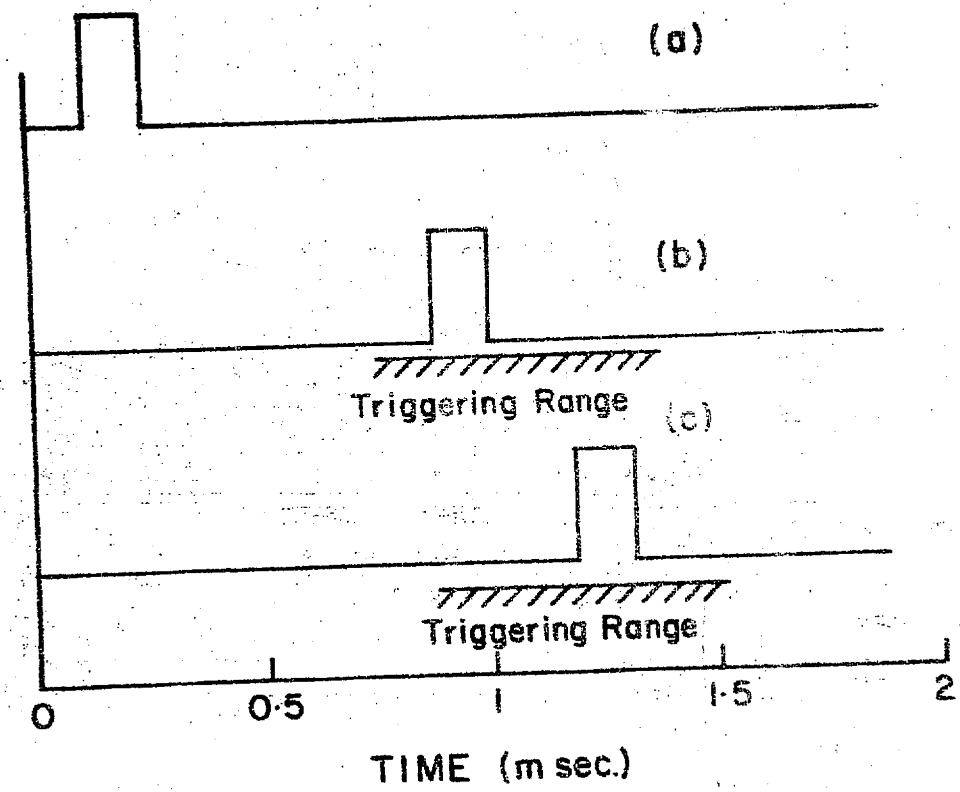


Figure 2

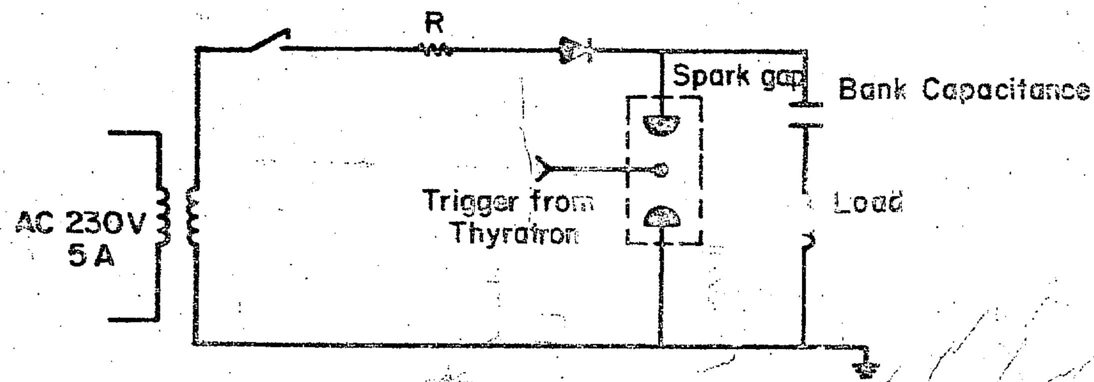

AC 230V
5 A
R
Spark gap
Bank Capacitance
Trigger from
Thyratron
Load

Figure 3

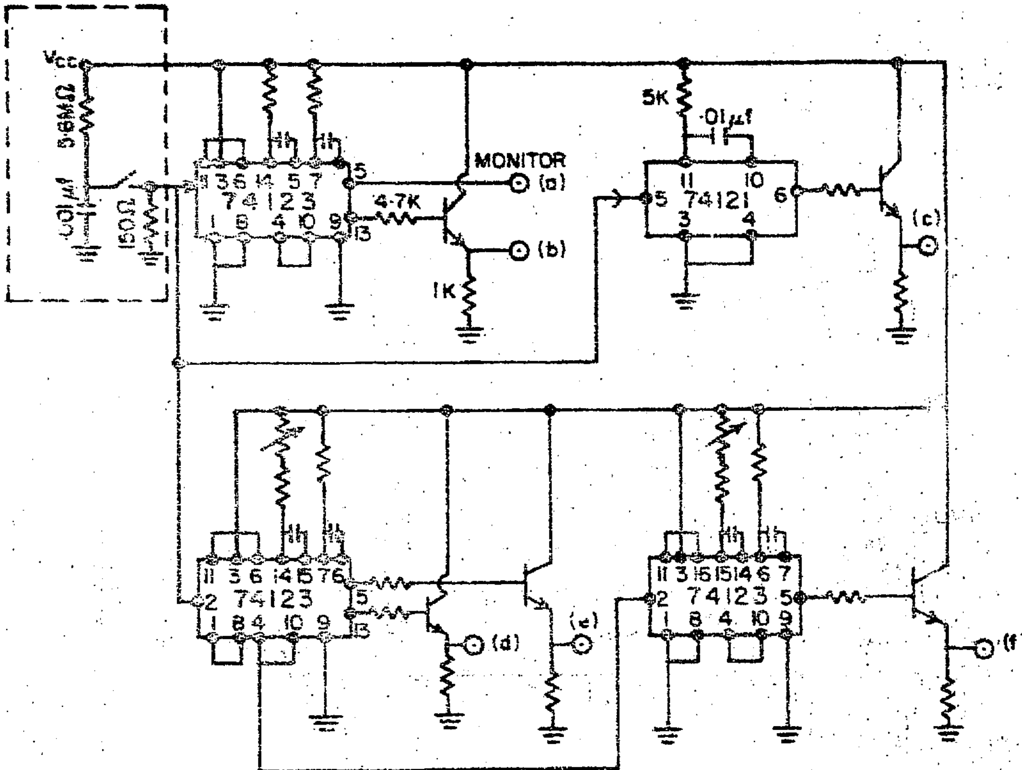
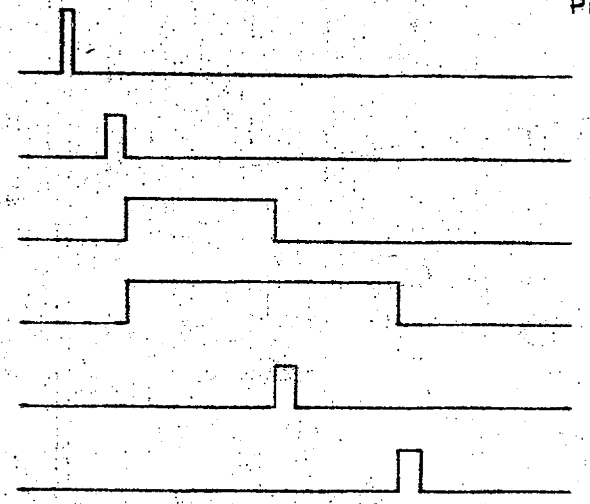

Vcc
5·6MΩ
·001µf
150Ω
74123
MONITOR
(a)
4·7K
(b)
1K
5K
·01µf
74121
(c)
(d)
(e)
(f)

Figure 4



Pulse	Pulse width	Purpose
a	1 μ sec.	Monitor (for triggering scope, diagnostics etc.)
b	10 μ sec.	To trigger SCR 1
c	0·1–1·5ms	To lock SCR 2
d	0·1–1·5ms	To lock SCR 3
e	10 μ sec.	To trigger SCR 2
f	10 μ sec.	To trigger SCR 3

Figure 5

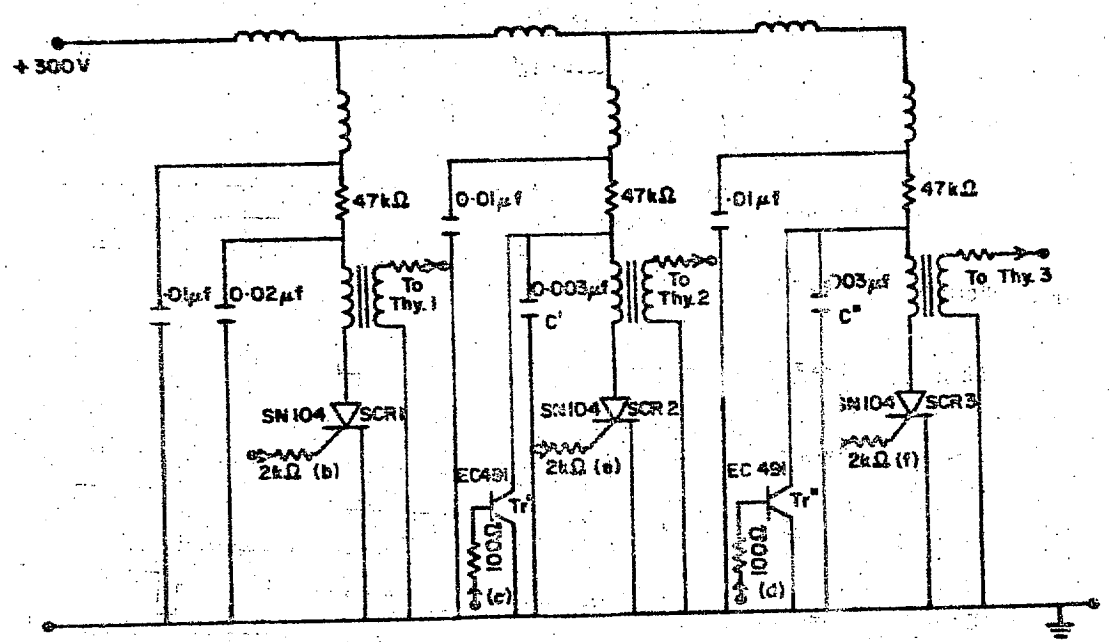

+300V
47kΩ
47kΩ
47kΩ
·01μf
0·02μf
0·01μf
0·003μf
C'
·01μf
·003μf
C"
To Thy. 1
To Thy. 2
To Thy. 3
SN104
SCR1
SN104
SCR 2
SN104
SCR 3
2kΩ (b)
2kΩ (e)
2kΩ (f)
EC491
Tr'
EC 491
Tr"
100Ω
(c)
100Ω
(d)

Figure 6

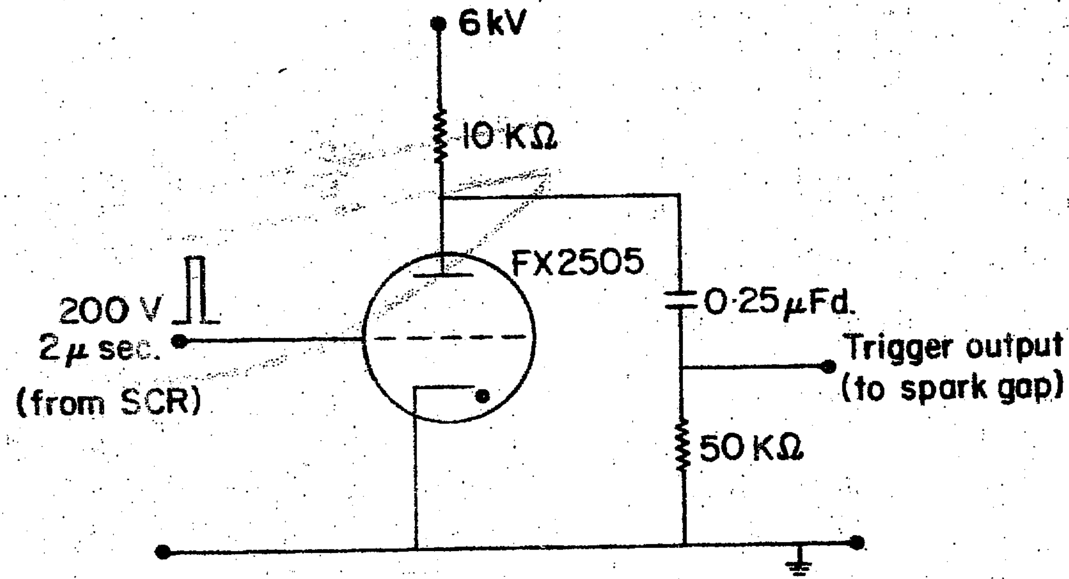

6 kV
10 KΩ
FX2505
200 V
2 μ sec.
(from SCR)
0·25 μFd.
Trigger output
(to spark gap)
50 KΩ

Figure 7

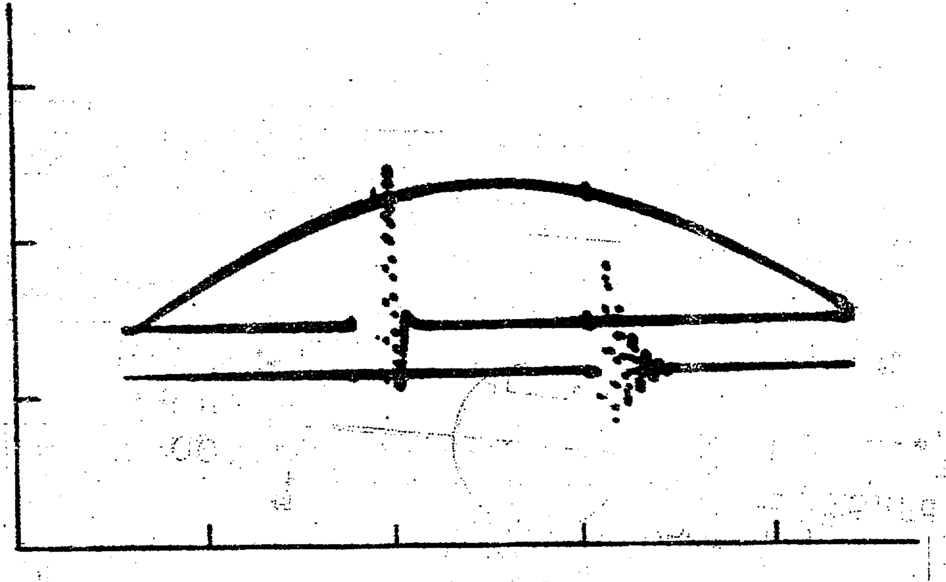


Figure 8

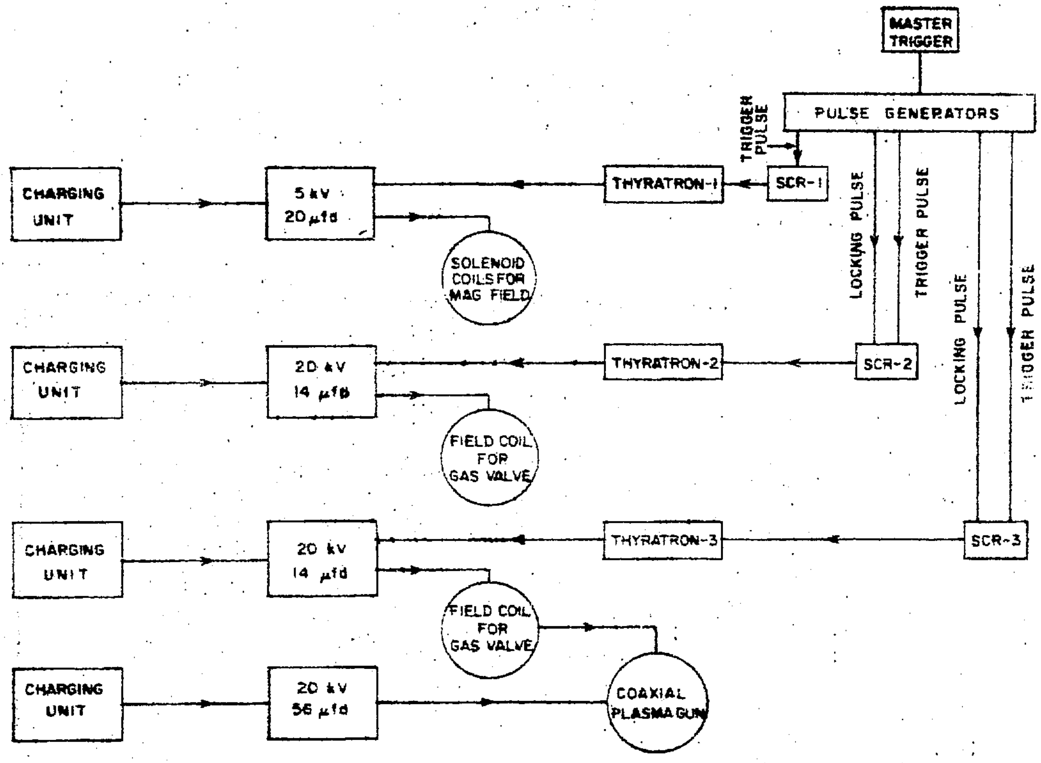

MASTER TRIGGER
PULSE GENERATORS
TRIGGER PULSE
SCR-1
THYRATRON-1
CHARGING UNIT
5 kV
20 μfd
SOLENOID COILS FOR MAG FIELD
LOCKING PULSE
TRIGGER PULSE
SCR-2
THYRATRON-2
CHARGING UNIT
20 kV
14 μfd
FIELD COIL FOR GAS VALVE
LOCKING PULSE
TRIGGER PULSE
SCR-3
THYRATRON-3
CHARGING UNIT
20 kV
14 μfd
FIELD COIL FOR GAS VALVE
CHARGING UNIT
20 kV
56 μfd
COAXIAL PLASMA GUN

Figure 9