Chapter 2

EXPERIMENTAL SET-UP AND DIAGNOSTICS

2.1 INTRODUCTION

Centre of Plasma Physics has a 2.2 kJ Mather type Dense Plasma Focus (DPF) facility [1] which was fabricated in collaboration with Bhabha Atomic Research Centre, Mumbai. The DPF facility can be broadly divided into two main parts:

1. Pulsed power driver and
2. Plasma focus tube and pumping system

2.2 PULSED POWER DRIVER

Pulsed power technology relies on power multiplication through time compression i.e. to convert a low power-long time input into high power-short time output. Voltages of the order of few tens of kilovolts with rise time of the order of microsecond are used to run our DPF experiments. The main components of the pulsed power driver are capacitor bank, charging unit, high power switches with compressed air system and control panel, which are discussed subsequently.

2.2.1 CAPACITOR BANK

For the generation of high temperature plasma in a DPF device a high current pulse is essential. Again, in order to transfer maximum energy to the plasma a high voltage is required. Such type of current and voltage can easily be obtained by discharging a capacitor through a desired load. To generate high current the capacitor should have low internal inductance and it should connect through a path of minimum circuit inductance [2].
The current $I$ flowing through a load at any time $t$ is given by

$$I(t) = I_0 \exp(-at) \sin(\omega t)$$  \hspace{1cm} (2.1)

Where,

$$I_0 = \frac{V_0}{\sqrt{L}} \left( \frac{F_v C}{L} \right)^{1/2}, \text{ peak current (for } L/C > R^2) \]

$$a = \frac{R}{2L}, \text{ decay constant}$$

$$\omega = \frac{1}{\sqrt{(LC)^{1/2}}}, \text{ ringing frequency}.$$  

In the above equations, $R$ is the total series resistance, $L$ is the total series inductance, $C$ is the bank capacitance, $V_0$ is the peak charging voltage and $F_v$ is the voltage reversal factor.

The time period of discharge is given by,

$$T = 2\pi (LC)^{1/2}$$  \hspace{1cm} (2.2)

and the stored energy of the capacitor is given by,

$$E = \frac{1}{2} CV_0^2$$  \hspace{1cm} (2.3)

It is seen from the equation (2.1) that to get high current, $V_0$ and $C$ should be high and $L$ should be low. But the increase in voltage above a certain limit will create insulation problem. Again, higher capacity capacitors with lower inductance are costly and use of more capacitors (in parallel connection) to get desired results (low inductance) creates design difficulties [3]. In view of the above-mentioned constraints and limitations, an oil filled capacitor of 7.1 $\mu$F, 40 kV having internal inductance of 40 nH is chosen for the present experiment. For the operation of DPF device, the capacitor is charged to a voltage of 25 kV. The specifications of the capacitor used are given in the Table 2.1.
## Table 2.1

**Specifications of the capacitor used in the present experiment**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Passoni &amp; Villa, Milano, Italy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance</td>
<td>7.1 μF ± 10%</td>
</tr>
<tr>
<td>Maximum charging voltage</td>
<td>40 kV</td>
</tr>
<tr>
<td>Energy</td>
<td>5.7 kJ ± 10 % (at 40 kV)</td>
</tr>
<tr>
<td>Voltage reversal</td>
<td>80 %</td>
</tr>
<tr>
<td>Series inductance (Capacitor + Spark gap)</td>
<td>~110 nH</td>
</tr>
<tr>
<td>Charge-discharge life</td>
<td>5 X 10⁴ shots</td>
</tr>
<tr>
<td>Ringing frequency</td>
<td>75 kH</td>
</tr>
<tr>
<td>DC life</td>
<td>2000 hrs.</td>
</tr>
<tr>
<td>DC insulation</td>
<td>&gt; 1000 MΩ</td>
</tr>
<tr>
<td>Dielectric insulation</td>
<td>Paper</td>
</tr>
<tr>
<td>Dielectric oil</td>
<td>Phenyl xylylethane</td>
</tr>
<tr>
<td>Height with spark gap</td>
<td>100 cm</td>
</tr>
<tr>
<td>Breadth</td>
<td>42 cm</td>
</tr>
<tr>
<td>Width</td>
<td>37 cm</td>
</tr>
<tr>
<td>Weight</td>
<td>100 kg</td>
</tr>
<tr>
<td>Cost</td>
<td>~ Rs. 6,00,000.00</td>
</tr>
</tbody>
</table>
2.2.2 CHARGING UNIT

The charging unit, which is used to energise the capacitor, includes a high voltage (HV) transformer, a rectifier-diode chain, motorized and fixed variac, and connecting and shorting switches. The circuit diagram of the DPF device is shown in the Fig.2.1.

The high voltage transformer is a step up transformer (Argo Transformer Co. Ltd., Mumbai) of output rating 33 kV RMS, 50 mA for 230 V RMS input voltage. The A.C. input of the main supply is fed to the high voltage transformer through an isolation transformer (1:1, 1.5 kVA), motorized and fixed variac and a miniature circuit breaker (MCB), respectively. The voltage of the step-up transformer rises gradually from zero to the required voltage level with the help of motorized variac. The fixed variac is introduced in between the motorized variac and MCB to limit the maximum voltage setting. The MCB connected in between the fixed variac and the high voltage transformer protects the motorised and fixed variac from damage due to excess back voltage from high voltage transformer. In order to convert A.C. high voltage to D.C., the output of the high voltage transformer is connected to a half wave rectifier through two parallely connected current limiting resistors (each of 100 kΩ, 12 W). The half wave rectifier is a diode chain consisting of six high voltage diodes each of rating 15 kV, 500 mA. The diode chain is kept inside a PVC tube filled with castor oil to reduce the production of corona discharge with air in the diode chain during the charging of the capacitor. The output of the diode chain is connected to the high voltage terminal of the capacitor by RG 58 (50 Ω) cables through a connecting/isolating switch. The connecting/isolating switch can be operated from a control panel by the combined operation of pneumatic cylinder, solenoid valve and compressed air system. For shorting the high voltage side of the capacitor to the ground after each
<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Line power supply</td>
</tr>
<tr>
<td>2.</td>
<td>Isolation transformer (1:1, 1.5 kVA)</td>
</tr>
<tr>
<td>3.</td>
<td>Motorized variac (8 A, 45 sec.)</td>
</tr>
<tr>
<td>4.</td>
<td>Fixed variac (8 A)</td>
</tr>
<tr>
<td>5.</td>
<td>MCB (2.5 A)</td>
</tr>
<tr>
<td>6.</td>
<td>HV transformer (33 kV, 50 mA)</td>
</tr>
<tr>
<td>7.</td>
<td>Resistor (100 kΩ, 12 Watt)</td>
</tr>
<tr>
<td>8.</td>
<td>Diode chain (6 nos., 15 kV)</td>
</tr>
<tr>
<td>9.</td>
<td>Connecting/Isolating switch</td>
</tr>
<tr>
<td>10.</td>
<td>Resistor (400 MΩ)</td>
</tr>
<tr>
<td>11.</td>
<td>Resistor (600 MΩ)</td>
</tr>
<tr>
<td>12.</td>
<td>Capacitor (7.1 μF, 40 kV)</td>
</tr>
<tr>
<td>13.</td>
<td>Pressurised spark gap</td>
</tr>
<tr>
<td>14.</td>
<td>PF tube</td>
</tr>
<tr>
<td>15.</td>
<td>Meter resistor (100 kΩ, 12 Watt)</td>
</tr>
<tr>
<td>16.</td>
<td>Voltmeter (0 – 50 kV)</td>
</tr>
<tr>
<td>17.</td>
<td>Safety diode (By 127)</td>
</tr>
<tr>
<td>18.</td>
<td>Shorting resistor (100 kΩ, 12 Watt)</td>
</tr>
<tr>
<td>19.</td>
<td>Grounding switch</td>
</tr>
<tr>
<td>20.</td>
<td>Safety inductor</td>
</tr>
<tr>
<td>21.</td>
<td>Safety resistor (1 kΩ, 10 Watt)</td>
</tr>
<tr>
<td>22.</td>
<td>Mother ground</td>
</tr>
</tbody>
</table>

**Fig. 2.1: Circuit diagram of the DPF device**
discharge a shorting switch is used which can be operated in the same way as the connecting/isolating switch. For low inductance connection between the capacitor and the load (plasma focus tube), two types of connections can be made viz. parallel plate connection and connection using coaxial cables [4]. Though parallel plate connection reduces the inductance, we have connected the capacitor and the load by fifteen parallely connected coaxial cables due to the reliability of insulation, reduce maintenance, reduce damage in case of failure, more flexible and better access to experiment [5]. The charging unit energize the capacitor to a voltage of about 25 kV and the capacitor is discharged through the load with the help of a high power switch.

2.2.3 HIGH POWER SWITCH WITH COMPRESSED AIR SYSTEM

To transfer energy from a capacitor to the load in high voltage pulsed power applications, special types of fast response, low inductance and high voltage switches are required. Commonly used switches in such purpose are trigatron, laser triggered configuration and field distortion spark gap [6]. Among these, field distortion spark gap is the reliable one. Field distortion spark gap is widely used in high voltage pulsed power applications due to its high voltage and high current capability, triggering capability over wide dynamic voltage range, minimum jitter, low inductance and reasonably long life time. A field distortion spark gap mainly consists of two coaxial electrodes separated by a dielectric. A third electrode is placed in between the two main electrodes. Electrodes used in such spark gap are generally coated with an alloy of tungsten, molybdenum or tantalum for long life and high repetition rate. The dielectric medium between the electrodes made to break down by increasing the voltage between the electrodes or by applying an external trigger to the third electrode. In the present work, a built in pressurized air spark gap [3] of distorted field type has been used. As shown in Fig.2.2, it consists of three coaxial electrodes separated from
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Fig. 2.2: Schematic of the spark gap with capacitor

Each other by ~ 40 mm. The middle electrode is kept at the half voltage point of the charging voltage by an external resistive divider, which can also be used as a trigger electrode. The central electrode is common point to the high voltage end and the capacitor. The outer electrode is connected to one side of the load. The whole electrode assembly is housed inside a ceramic casing and rigidly fixed at the top of the capacitor. The compressed dry air is fed in to the spark gap through inlet channel and removed from it through outlet channel as shown in Fig. 2.2. These channels are connected to electrically operated solenoid valve through PVC tubes of 4 mm diameter hole. During operation the spark gap is pressurised to around three atmospheric pressures and is triggered by the release of pressure. The self-breakdown voltage of the system at normal pressure and temperature is ~21 kV. The life of spark gap used in the present work is ~10^4 shots. In the present experiment, an air
compressor supplying air at about three atmospheric pressures is used to pressurise the spark gap as well as the pneumatic cylinders. Before applying the compressed air to the spark gap and to the pneumatic cylinder, it is filtered through a preliminary air filter and then dried through a silica gel cylinder and finally filtered with a pair of filter made from polycarbonate material (Shavo Norgren make).

2.2.4 CONTROL PANEL

The operation of DPF device can be performed from a control panel. The control panel contains all the switches for operation that are fitted on a board inside a grounded steel cage, positioned at a few meters away from the DPF circuit assembly. Fig.2.3 indicates various parts of the control panel. Operations like charging the capacitor, discharging it through the plasma focus device, allowing compressed air to the different units, shorting the high voltage side of the capacitor to the ground etc. are performed from the control panel with the help of light indicating switches. A voltmeter fixed on the control panel directly indicates the charging voltage of the capacitor.

2.3 PLASMA FOCUS TUBE AND PUMPING SYSTEM

Plasma focus (PF) tube mainly consists of a coaxial electrode assembly kept inside a vacuum chamber. Geometrical designing of the PF tube is necessary to transfer maximum energy from the capacitor to the load, so that a very high density and high
temperature plasma can be obtained. Following important factors should be considered while designing a PF tube.

a) The working gas pressure inside the tube should be high enough to form a good current sheet.

b) The capacitor discharge current should attain its maximum approximately at the time of focus formation.

The first criteria is simply to keep the focus tube at high pressure (~0.1 - 1.0 torr) so that a good current sheet, as a result good focus, is produced and the second criteria can be fulfilled by appropriate designing of the electrodes. Several formulations regarding the design of a PF tube for its optimum operation is available in previously reported literature [4, 5, 7-9]. The best formulation among them [5] is

\[ CV_o^2 / pl = K_1 \]  
\[ CV_o / r p l^{1/2} = K_2 \]

where \( C \) is the capacitance of the capacitor, \( V_o \) is the charging voltage, \( p \) is the operating gas pressure, \( l \) is the length of the electrode and \( r \) is the radius of the inner electrode. Here \( K_1 \) and \( K_2 \) are two constants, which can be obtained from other efficient existing DPF device. In designing the PF tube for best focussing, annular spacing between the coaxial electrodes and the length of the insulator also plays an important role. An annular spacing of 25 mm between the coaxial electrodes gives the best result [10]. Again, for a voltage of 4 kV an insulator of length 1 cm leads to symmetric and homogeneous current sheet formation around the insulator [11].

Considering all the above-mentioned requirements, a PF tube is designed for 2.2 kJ Mather type DPF device, taking in to account the constants \( K_1 \) and \( K_2 \) from an existing DPF device of Bhabha Atomic Research Centre, Mumbai. The dimensions of the different parts of PF tube are given in Table 2.2. The 3-D view of PF tube used in
the present experiment is shown in Fig.2.4. The coaxial electrode assembly consists of an anode surrounded by twelve cathode rods arranged in a squirrel cage fashion. In the

<table>
<thead>
<tr>
<th>Components</th>
<th>Length</th>
<th>Diameter</th>
<th>Material(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anode</td>
<td>115 mm</td>
<td>21 mm (O.D.)</td>
<td>Stainless steel, brass, tungsten, copper and aluminium</td>
</tr>
<tr>
<td>Cathode rod</td>
<td>110 mm</td>
<td>90 mm (O.D.)</td>
<td>Stainless steel, brass</td>
</tr>
<tr>
<td>Insulator sleeve</td>
<td>45 mm</td>
<td>21 mm (I.D.)</td>
<td>Borosil</td>
</tr>
<tr>
<td>Vacuum chamber</td>
<td>Volume</td>
<td>~ 6 litres</td>
<td>Stainless steel</td>
</tr>
</tbody>
</table>

*Fig.2.4: 3-D view of the PF tube*
present experiment most of the investigations are carried out using different designed anode tips (hemispherical, solid and hollow) of various materials (brass, stainless steel, tungsten, copper and aluminium). An insulator (borosil glass) separates the two electrodes at the bottom end. A photograph of the different designed anodes and insulator fitted anode is shown in Fig.2.5. The whole electrode assembly is kept inside a stainless steel vacuum chamber of volume 6 litres. The vacuum chamber has six side ports. A photograph of the top view of PF tube is shown in Fig.2.6. The schematic
of PF tube along with discharge circuit is shown in Fig. 2.7. A rotary-diffusion pumping system is used to pump down the vacuum chamber. A needle valve is used to insert the gas inside the vacuum chamber and a McLeod gauge measures the filling gas pressure inside the vacuum chamber. The rotary-diffusion pump, the needle valve and the McLeod gauge are connected to one of the side ports of the vacuum chamber.

Fig. 2.7: Schematic of the PF-tube along with discharge circuit
using a multi-port facility as shown in Fig.2.7. The other five side ports of the vacuum chamber can be used simultaneously for diagnosis. The gases used in the experiment are high purity nitrogen, hydrogen and argon. The DPF device is operated in a static filling pressure mode for economy. The PF tube is evacuated for refilling after each discharge to remove the impurity due to material erosion from the anode surface and the chamber wall. A photograph of CPP’s DPF unit is shown in Fig.2.8.

![Fig.2.8: A photograph of DPF unit](image)

2.4 DIAGNOSTICS

Plasma diagnostics play a vital role in experimental plasma physics research. DPF device is a pulse plasma-producing device that produces high temperature and high-density plasma, and lasts for a few tens of nanoseconds. To diagnose such types of short-lived plasmas, fast response sensitive diagnostic tools are essential. Again, to study several plasma properties using most of the diagnostic tools that gives electrical signals the first and foremost requirement is the signal recorder with appropriate
bandwidth and sampling rate. In the present experiment, a four-channel 500 MHz, colour digital phosphor oscilloscope with a sampling rate of 1 Gs/Sec (Tektronix TDS754-D) and a two-channel 100 MHz digital oscilloscope with a sampling rate of 500 Ms/Sec (Tektronix TDS320) have been used to record the electrical signals. The oscilloscopes are kept inside a grounded steel casing near the control panel. The grounded steel casing reduces the EM-noise entering into the oscilloscope during the DPF device operation. The diagnostics used to study the plasma parameters in the present work are:

i) Rogowski coil

ii) Resistive voltage divider

iii) Magnetic probe

iv) Diode X-ray spectrometer

v) Pinhole camera

vi) Faraday cup

The first two basic diagnostics (Rogowski coil and Resistive voltage divider) are explained in this section and the rest are described in the subsequent chapters.

2.4.1 Basic Electrical Diagnostic Methods

In the DPF device, plasma heating is achieved by the passage of intense current pulses through the plasma. This heating mechanism involves the magnetic compression that is inductive in nature, and/or the Joule heating which is resistive in nature [4]. In any case, one may consider the plasma as an active element in the discharge circuit with its electrical properties represented by the combination of a variable resistor ($R_p$) and a variable inductor ($L_p$), which is illustrated in the equivalent circuit of the DPF device (Fig.2.9) where $R_e$ and $L_e$ are the external circuit resistance and inductance respectively. When the switch $S$ is closed, the energy is initially stored in the capacitor
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C and then discharge through the circuit. This discharge current flowing through the circuit is mainly affected by the conditions of the plasma. Thus a measurement of the discharge current reveals information concerning the dynamic changes of the plasma. Again, the transient voltage across the plasma is directly related to the plasma conditions. Thus combined interpretation of the measured current and voltage waveforms is usually sufficient for basic dynamics study. In the present experiment, a Rogowski coil and a resistive voltage divider are used to display the current and voltage waveform respectively, which are explained subsequently.

2.4.1.1 Rogowski Coil (Current Probe)

Rogowski coil [12-14] is mainly used to measure the high current due to capacitor discharge. In general, it is a multi-turned solenoid bent into the shape of a torous encircling the current to be measured. It works on the simple principle based on Faraday's law of electromagnetic induction. In the present experiment, a calibrated miniature Rogowski coil [15] is used to measure the discharge current. It is a four-turned solenoid placed in the path of discharge current such that maximum flux enters into it (to produce a corresponding induced emf). The design of Rogowski coil is shown in Fig.2.10 (a). The coil is terminated with a low inductance resistor ($r$) and fed to the oscilloscope via a 50 $\Omega$ impedance matching resistor. The equivalent circuit is given in Fig.2.10 (b), where $L_R$ and $r_R$ are respectively the inductance and resistance of the coil, and $i$ is the circuit current of the coil. The circuit equation of the Rogowski coil assembly can be written as:

Fig.2.9: Equivalent circuit of DPF device

Fig.2.10 (a): Design of Rogowski coil
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\[
L_R \frac{di}{dt} + (r_R + r)i = k \frac{di}{dt}
\]  

(2.6)

where \( I \) is the discharge current and \( k \) is a constant.

If \( L_R \frac{di}{dt} \gg ((r_R + r)i \), then from equation (2.6) we can obtain \( i = \frac{k}{L_R} I \), so the output voltage will be

\[
V_R = ri = r \frac{k}{L_R} \times I = k_i I
\]

(2.7)

Under this condition the Rogowski coil acts as a current transformer.

Again, if \((r_R + r)i \gg L_R \frac{di}{dt}\) , then from equation (2.6) the output voltage will be

\[
V_R = ri = \left( \frac{rk}{r_R + r} \right) \frac{di}{dt}
\]

(2.8)

In this case, the Rogowski coil can be used to measure the derivative of current \((dI/dt)\).
Oscillogram of the derivative of current waveform \( (dl/dt) \) and the current waveform \( I(t) \) for a DPF discharge is shown in Fig. 2.11. The dip in the negative side of the current signals is directly related to the pinch compression. Maximum dip in the current waveform is obtained for good focussing (maximum pinch compression). This variation in the dip of the current waveform occurs due to the rapid increase of the plasma inductance at the time of pinching.

![Oscillogram of dl/dt and I(t) signals](image)

**Fig. 2.11: Oscillogram of \( dl/dt \) and \( I(t) \) signals**

The Rogowski coil, when used, as a current transformer is required to calibrate for absolute measurement. The DPF device operated at high pressure resembles closely to a L-C-R discharge system. For known charging voltage \( (V_0) \) and capacitance \( (C) \) the coil can be calibrated for absolute measurement from the relation [16]:

\[
I_o = \frac{\pi CV_0(1 + F_v)}{T}
\]  

(2.9)

Where \( I_o \) is the actual peak discharge current flowing through the circuit, \( T \) is the time period of discharge and \( F_v \) is a voltage reversal factor, which is the ratio of the voltage
of any two consecutive peaks. Thus measuring $F_v$ and $T$ from the current waveform, $I_o$ can be obtained. In our case the value of $F_v$ and $T$ are $\sim 0.9$ and $\sim 8.8$ $\mu$s respectively.

Again by recording the time period of discharge from the oscillagram, the external inductance $L_e$ of the circuit may be calculated from the following relation

$$L_e = \frac{T^2}{4\pi^2 C}$$

(2.10)

The measured peak discharge current in the present experiment is 138 kA and the external circuit inductance is 233 nH.

2.4.1.2 RESISTIVE VOLTAGE DIVIDER (VOLTAGE PROBE)

The transient voltage developed across the plasma can be measured by using a simple resistive voltage divider [17]. Schematic of the resistive voltage divider used in the present work is shown in Fig.2.12. It consists of a chain of five 1 kΩ, 2 Watt carbon resistors connected in series with a low inductance shunting resistor (50 Ω, 2 Watt) connected in between the 1 kΩ resistor and the ground as shown in Fig.2.12. The resistive divider is enclosed in a PVC pipe, which is again shielded with a grounded aluminium foil. The whole assembly is enclosed in a Perspex tube for the electrical insulation. The resistive voltage divider is connected at the lower end of the focus tube across the anode and cathode flanges.

![Schematic of the resistive voltage divider](image-url)
The voltage attenuation factor \( A_v \) of this probe can be written as

\[
A_v = \frac{r_s}{r_s + R_t}
\]  

(2.11)

Where \( R_t \) is the total series resistance of the chain and \( r_s \) is the shunting resistance. If \( r_s \ll R_t \), the equation can be written as

\[
A_v = \frac{r_s}{R_t}
\]

The resistive voltage divider in our case attenuates the voltage signals approximately by 100 times. The output of this resistive voltage divider is connected to the oscilloscope through a \( \pi \)-attenuator, which attenuates the signal further by 22 times. A typical oscillogram of the derivative of current signal \( (dl/dt) \) along with voltage probe signal \( V(t) \) for a single DPF discharge is shown in Fig.2.13. The voltage probe signal has a sharp peak in its positive cycle that confirms good focussing of the DPF device. In the DPF device during the radial collapse phase a very high voltage is developed due to the rapid increase in the plasma inductance, resulting a sharp distinct current dip and voltage peak [18].

![Fig.2.13: Oscillogram of current and voltage signals](image)
In the DPF operation, the derivative of current \(\frac{dl}{dt}\) signal and the voltage signal \(V(t)\) across the focus tube are monitored for every discharge. From these signals or by applying some simple calculations based on them, a great deal of information such as the transit time of each phase, focusing quality and gross dynamics of the plasma focus can be obtained. Furthermore, these signals are used to correlate with other time resolved signals to provide more information as explained in the subsequent chapters. The dip in Rogowski coil signal and peak in voltage probe signal helps in ascertaining good focusing action in the DPF discharge. The working gas pressure for which a good focusing takes place is termed as the optimum pressure for that particular operating gas. The optimum pressure for different working gas is different. The height of the peak in voltage probe signal and the dip in Rogowski coil signal is a maximum at optimum pressure of an operating gas. Thus the pressure optimization for different gas can be performed with the help of current and voltage signals. We have optimized our DPF device for hydrogen, nitrogen and argon gases and the optimum pressures are given in the Table 2.3.

\textbf{Table 2.3}

\textbf{Optimum operating pressure for different filling gas}

<table>
<thead>
<tr>
<th>Gas used</th>
<th>Pressure in torr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N\textsubscript{2})</td>
<td>0.3 – 0.4</td>
</tr>
<tr>
<td>Argon (Ar)</td>
<td>0.2 – 0.3</td>
</tr>
<tr>
<td>Hydrogen (H\textsubscript{2})</td>
<td>0.8 – 0.9</td>
</tr>
</tbody>
</table>
REFERENCES


