Chapter 6

Overall conclusion and future works

This thesis reports the results of X-ray and neutron emission from an existing 2.2 kJ Mather type Plasma Focus (PF) device at “Centre of Plasma Physics- Institute for Plasma Research” PF facility. The experimental works reported in this thesis were carried out under different working conditions. A cylindrical vacuum photodiode (VPD) has been developed to study the X-ray emission from PF device by changing different anode design. These experimental works were carried out in hydrogen plasma. Similarly the neutron emission from PF device was carried out in deuterium medium.

In order to study the soft X-ray emission from PF device, a simple low cost soft X-ray detector called vacuum photodiode (VPD) has been developed and tested. We have made an attempt to find out the effectiveness of VPD in PF device as an X-ray detector and by doing this we could find out the condition for reducing its size and increasing the efficiency. The cathode-anode gap in the lateral direction of cylindrical VPD is also found to be important to increase the performance of VPD in a relatively higher-pressure device such as PF device. The effect of charge particles from PF device also influences the detector in a filter less condition. The efficiency of the VPD can be increased by choosing the right kind of filter. The detector has been used to study the X-ray emission from PF along with other conventional detectors like PIN diode. It has been observed that both the
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detectors were able to acquire similar types of X-ray pulses from the PF device. The
response time of the VPD is found to be around 0.3 ns which is found to be more faster
than PIN diode. We have also determined the average X-ray photon energy at the location
of the detector and it is found to be around \(1.34 \pm 0.06\) keV of the hydrogen plasma.

The effect of anode shape on pinch structure and X-ray emission of PF device is
observed with four different anode tips namely cylindrical, diverging, oval and converging.
The images of the pinch region were captured by a triple pinhole camera which can capture
three images simultaneously of the same pinch region. In the experimentation, the three
images of plasma column in a single shot were captured with Al filters of thickness of 2, 4
and 6 \(\mu\)m in front of the pinholes which helps to observe X-ray emitting zone with the
variation of intensities. From the experimental results it is seen that X-ray emission is
higher for converging and cylindrical anode tips compared to diverging and oval anode tip.
The oval and diverging anode tips are observed to be more conducive for the formation of
instabilities \((m = 0, 1)\) and hotspots. The hard X-ray emission from different anode shape
was observed by employing a photomultiplier tube combined with scintillator. It is
observed that in most of the PF shots the hard X-ray emission appeared with multiple
pulses. In most of the shots (68%) with oval anode, the hard X-ray signal shows multiple
pulses followed by diverging anode (48%), cylindrical anode (36%) and converging anode
(28%). The more observed multiple pulses of hard X-ray signal with oval and diverging
anode imply that the formation of instabilities is more than the other anode designs and
proves the results of triple pinhole camera. The effective hard X-ray photon energy (105,
85, 77 and 121 keV for cylindrical, diverging, oval and converging anode tips, respectively)
was also estimated by the radiography method for all the anode tip designs. The
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measurement of hard X-ray for different shaped anodes gives a qualitative idea of induced accelerating field, which is generated during radial compression phase. The energy of the hard X-ray is related to the energy of electron beam bombarded to the anode edge, which is in turn related to the strength of the induced accelerating field. So in case of converging anode the induced accelerating field is more and in case of diverging anode it is less.

The performance of a VPD has been demonstrated as an X-ray diagnostics with the quantitative measurement of X-ray emission from PF device. The VPD has been used to measure electron temperature, soft X-ray energy and total radiated power of PF device for different anode tips. The estimated electron temperatures are found different for different anode tips, as there exists a different optimized operating pressure corresponding to each anode tip. The calculated value of soft X-ray photon energy is found to be 1.28, 3.0, 1.2 and 1.1 keV respectively for cylindrical, diverging, oval and converging anode tip from the experimental value of electron temperature. The total radiated power is deduced from the vacuum photodiode signals and it is found to be different for different anode shapes. It is observed that the total radiated X-ray power of diverging and oval anode lies in between cylindrical and converging anode. The time resolved measurement of X-ray emission by using VPD demonstrates its utility as an alternate X-ray diagnostic tool in PF device. The results obtained by using VPD have shown the importance in the context of the detector's selection as an X-ray detector for ITER reactor.

The experimental study on neutron emission reveals that ions play an important role in neutron emission from PF device. It seems that neutron production in PF device strongly depends upon the filling gas pressure. An interesting correlation between hard X-ray and neutron has been observed. It is observed that when neutron pulse is very intense the
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Corresponding hard X-ray pulse is small and when neutron pulse is small hard X-ray pulse appeared to be intense. The difference of theses hard X-ray and neutron intensities is due to the plasma diode formation during pinching. The existence of two neutron pulse with different intensities and pulse widths in axial and radial directions are confirmed. The neutron yield and energy are found to be highly anisotropic with a factor >1. The anisotropy of neutron emission suggests that the beam target mechanism is mainly responsible for the neutron production in our PF device. The emission of two pulse of neutron suggests that there may be another mechanism of neutron production in PF device.

**Future Works**

The VPD developed in the present work proven valuable to be soft X-ray diagnostic in harsh environment of PF device. This simple and low cost detector gives a good photon energy response with Aluminum photocathode and small anode cathode annular gap. Thus, VPD can be developed to an array to study the soft X-ray emission from PF device. The response of the detector can be further tested by using different photocathode with good quantum efficiency and by decreasing the annular space between anode and cathode. Better energy resolution can be achieved with good combination of filter material in front of the photocathode. The soft X-ray detection and its time resolved measurement from PF device by using VPD may be useful for its future use in a fusion reactor such as ITER along with broad range of sensitivity from UV to soft X-rays.

Furthermore, the anode shape used in the present study can be used to study the neutron emission from the PF device. As from the present study it is seen that enhanced insatiability, hotspot formation and X-ray emission is found to be more in case of different
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shaped anodes. An extensive study of correlation between neutron emission with insatiability, hot spot and X-ray generation can be done with these different shaped anodes.