CHAPTER 4

QUALITATIVE STUDY ON THE DISCHARGE CHARACTERISTICS OF UMVS

The discharge characteristics of the UMVS with several electrode configurations are tried to optimise the regularity of the hot spot formation. The following requirements are used in determining the best configuration :

I) The system can be charged to its operating voltage and initiated to breakdown as frequent as possible.

II) The x-ray signal(s) emitted is(are) of medium to high intensity.

III) The signals are emitted at or near the current peak.

A maximum of 50 discharges is recorded for each setup. During this period, there are self-breakdowns while charging or when the capacitor is fully charged. Sometimes when the system is fully charged and triggered, there are no x-rays emitted although there is a breakdown. There are also instances where no breakdown occurs when the system is charged-up and triggered.

The 50 shots recorded are discharges that have x-ray emissions from pre-breakdown electron beams, secondary electron beams, plasma or from all of these. The number of self-breakdowns for each setup is used for determining the electrode configuration that can hold the charging voltage across the gap.

The initial plan was to use cathode apertures ranging from 2 mm to 10 mm and interelectrode spacing of 2 mm. Later, it is found that for cathode aperture of 6 mm, the system could not be charged to its full voltage as frequent as possible. There are many self-breakdowns. Therefore, the experiments on cathode apertures of 6 mm to 10 mm are not carried out. On the other hand, for cathode aperture of 2 mm, there are many self-breakdowns, too.

Since the results for cathode apertures of 3, 4 and 5 mm are encouraging, these apertures are used for the rest of the investigation. To find the best setup, the interelectrode spacing is varied. It is found that the system could not be triggered to breakdown for A-C gap of 4 mm. Therefore, interelectrode spacing of 1, 2 and 3 mm are used.

During these series of experiments, the diagnostics used extensively are the magnetic probe to monitor the *dI/dt* signal, the 3 end-on PIN diodes to determine the electron temperature and the side-on PIN diode to observe the weak emissions. The soft x-ray measurement and x-ray pinhole imaging are not carried out. Therefore, it could not be determined whether the emission is from the plasma cloud or from the hot spot. However, the x-ray emission due to the plasma, the pre-breakdown electron beam or the secondary electron beam is determined based on the pinhole imaging that is carried out later (see Chap. 5) and from previous studies *[Ong, 1992]*. The x-ray signals emitted before 100 ns is believed to be due to the pre-breakdown electron beam or secondary electron beam or both, whereas, the emission of x-rays after 100 ns is expected to be originated from the plasma.

4.1 : Characteristics of each setup

4.1.1 : Cathode aperture = 3 mm, A-C gap = 1 mm (3-1)

For this setup, there are many self-breakdowns in the initial stage of operation. From the 50 discharges recorded, 70% have x-ray emission from the plasma but the signals are weak. The intensity of x-rays emitted due to the pre-breakdown or secondary electron beams are weak too. Most of the plasma emission is between 100 - 300 ns after the breakdown, that is, during the first half of the rising edge of the current cycle. This means that the plasma is formed at low currents. There are a few medium intensity emissions at 300 - 400 ns interval and none at all near or at the current peak. The electron temperature is estimated between 2.1 - 2.4 keV.

4.1.2 : Cathode aperture = 3 mm, A-C gap = 2 mm (3-2)

There are many self-breakdowns, too. 74% of the discharges have plasma emission. Some discharges have multiple dips in the *dI/dt* signal. There are emission of x-rays corresponding to these dips. Probably, there are multiple pinches occurring for these discharges. The x-ray emission from the pre-breakdown electron beam and/or secondary electron beam is quite strong. The plasma emissions occur throughout the rising edge of the current and after the current peak. There are more emissions near the current peak. The intensities of the emitted signals are stronger and most of the strong signals are emitted between

200 - 400 ns intervals. This is an improvement from the previous setup. The estimated electron temperature is between 2.1 - 2.6 keV.

4.1.3 : Cathode aperture = 3 mm, A-C gap = 3 mm (3-3)

For this setup, the experiment is stopped after sometime because there are no discharges. Initially, there are many self-breakdowns but after a few discharges no breakdown could be initiated although the full voltage is maintained across the gap. From the few shots fired, multiple dips in the *dI/dt* signal are observed but the signals are weak. The x-ray emission due to the secondary electron beam is quite intense. The electron temperature could not be estimated because there is hardly any good shot.

4.1.4 : Cathode aperture = 4 mm, A-C gap = 1 mm (4-1)

The experiment for this setup is stopped after sometime because it does not breakdown when initiated. Similar to the 3-1 setup, initially there are many self-breakdown but after a few discharges the voltage can be 'held' across the electrodes and no discharge can be initiated. The x-ray signals from the pre-breakdown electron beam and the secondary electron beam are of low intensity. For the discharges with dips in the *dI/dt* signal, the end-on PIN detected weak signals or sometimes none at all though the side-on PIN detected these signals. The electron temperature could not be estimated too because there is no good shot.

4.1.5 : Cathode aperture = 4 mm, A-C gap = 2 mm (4-2)

This setup shows an improvement in holding the voltage across the gap. This can be deduced from the significant reduction in the number of self-breakdowns. Also, the output from this setup is better. From the 50 discharges, 92% have strong x-ray emission from the plasma. The signals are emitted throughout the first quarter cycle of the current and also after the current peak. There are also more x-rays emitted at or near the current peak. Most of these signals have large amplitudes. The x-ray emission from the secondary electron beam is also quite strong. The estimated electron temperature is between 2.3 - 2.6 keV.

4.1.6 : Cathode aperture = 4 mm, A-C gap = 3 (4-3)

This setup has discharges with multiple dips in the *dI/dt* signal. The emissions from the plasma and the secondary electron beam are quite strong. However, the experiment is stopped after sometime due to the inability of the system to breakdown after a few discharges. The estimated electron temperature is between 2.1 - 2.4 keV.

4.1.7 : Cathode aperture = 5 mm, A-C gap = 1 mm (5-1)

During the early stages, there are many self-breakdowns while charging between 10 - 20 kV. X-rays due to the pre-breakdown electron beam are also emitted. From the 50 discharges, 80% of the discharges have emission from the plasma but only a few shots have strong signals. Most of the medium intensity emission is at 100 - 400 ns intervals. Although there are a few discharges with emission near the current peak however, the emitted intensity is low. The estimated temperature is between 2.0 - 2.4 keV.

4.1.8 : Cathode aperture = 5 mm, A-C gap = 2 mm (5-2)

The number of self-breakdown increased after about 30 - 40 shots. The x-ray emission due to the pre-breakdown electron beam and the secondary electron beam is very strong. 72% of the discharges have plasma emission, with some shots having multiple dips in the *dI/dt* signal. The emissions from these multiple dips are very strong, too. There are also plasma emissions after the current peak but most of the emission is at 300 - 400 ns intervals. The estimated electron temperature is between 2.0 - 2.3 keV.

4.1.9 : Cathode aperture = 5 mm, A-C gap = 3 mm (5-3)

The x-ray emission due to the pre-breakdown electron beam and the secondary electron beam is quite strong with multiple signals in some shots. The plasma emission occurs in about 70% of the total discharges. There are also several discharges with multiple dips emitting strong x-ray signals. Most of the signals are between 100 - 400 ns interval. This setup could not be initiated to breakdown after 40 - 50 shots. The estimated electron temperature is between

2.2 - 2.5 keV.

4.2 : Characteristics of various cathode aperture with same A-C gap

4.2.1 : A-C gap = 1 mm

The number of self-breakdown has reduced when the cathode aperture is enlarged from 3 mm to 5 mm (Fig. 4.1) but it's not conclusive because for cathode aperture of 4 mm the experiment is not carried out after sometime. This is because there are no x-ray signals emitted although breakdown occurs. From the two series (3-1 and 5-1) it shows that the number of self-breakdowns has reduced, therefore, suggesting that the system could hold the full voltage better as the aperture is increased. Also, it is found that there is a small increase in the number of signals with greater amplitude and the time of occurrence of some signals as shown in Fig. 4.2 (The percentage is the ratio of the number of discharges with x-ray emission at the specified time period and the total number of discharges.). This seems to suggest that probably by increasing the cathode aperture, the ability of the system to hold the full voltage across the gap is improved for a particular gap. Furthermore, there is a possibility that the output could be enhanced by increasing the cathode aperture.

4.2.2 : A-C gap = 2 mm

For the cathode aperture used, the 3-mm cathode aperture has the most

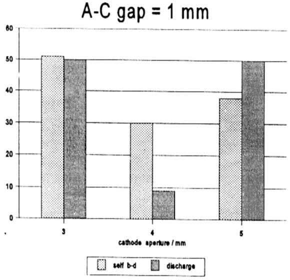

Fig. 4.1 : The total number of discharges with emission and total number of self-breakdowns for cathode apertures of 3, 4 and 5 mm.

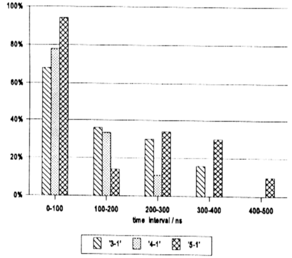

Fig. 4.2 : Percentage of discharges that have emission of x-ray at the specified time intervals.

number of self-breakdown which means that for this configuration, the ability of the system to hold the charging voltage is not good. With 4 mm cathode aperture, the number of self-breakdowns has reduced. If compared with the previous setup (3-1, 4-1 and 5-1); it is expected that for 5 mm cathode aperture the number of self-breakdowns should be the smallest but on the contrary, it is not. It is greater than for 4 mm but less than for 3 mm (Fig. 4.3). The output for these configurations is better than for A-C gap = 1 mm with cathode aperture = 3, 4, 5 mm. There are more signals with greater amplitude. There is also an increase in the number of signals at intervals 400 - 500 ns and 500 - 600 ns (Fig. 4.4), which means that there are more hot spots formed at or near the current maximum. Among these three, the 4-mm cathode aperture is the best because there are more signals at 400 - 600 ns intervals.

4.2.3 : A-C gap = 3 mm

For cathode apertures of 3 and 4 mm, only a few shots are fired. After that, there are no breakdowns. From these discharges it is found that there are only a few shots with strong signals but since the experiment could not be carried out anymore, it cannot be decided whether these configurations would give a better output than the others. For 5 mm cathode aperture, the experiment is stopped after some attempts because breakdown cannot be initiated.

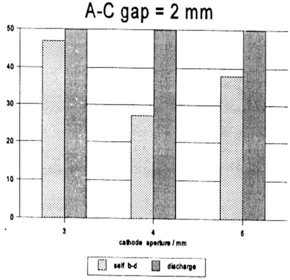

Fig. 4.3 : The total number of discharges with emission and total number of self-breakdowns for cathode apertures of 3, 4 and 5 mm.

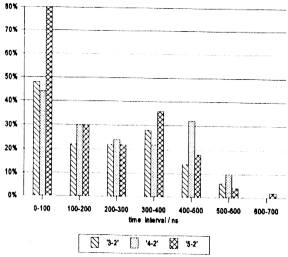

Fig. 4.4 : Percentage of discharges that have emission of x-ray at the specified time intervals

4.3 : Characteristics of various A-C gap with same cathode aperture

4.3.1 : Cathode aperture = 3 mm

The variation of A-C gap does not have much effect on the ability of the system to hold the voltage across the gap, Figure 4.5 . There are many self-breakdowns for both 3-1 and 3-2 configuration. For the 3-3 setup, it cannot be decided because no breakdown can be initiated after a few discharges. However, there is a slight improvement in the number of discharges that have emission near the current peak for the 3-2 setup compared to 3-1, Figure 4.6.

4.3.2 : Cathode aperture = 4 mm

For setups 4-1 and 4-3, the discharges could not be initiated after firing some shots, therefore, the effect of A-C gap for cathode aperture of 4 mm in holding the charging voltage cannot be determined, Figure 4.7. However, from Figure 4.8, it can be seen that there are more emissions at or near the current peak for the 4-2 configuration.

4.3.3 : Cathode aperture = 5 mm

There is not much variation in the ability of the system to hold the charging voltage for the different gaps used, Figure 4.9. Also, the emissions are almost alike for all the A-C gaps, Figure 4.10. Overall, there is not much

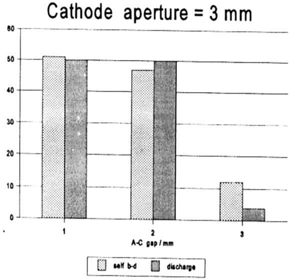

Fig. 4.5 : The total number of discharges with emission and total number of self-breakdowns for interelectrode spacings of 1, 2 and 3 mm.

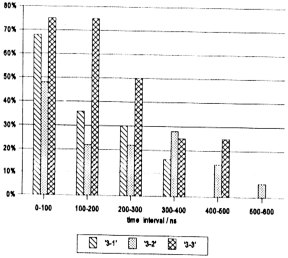

Fig. 4.6 : Percentage of discharges that have emission of x-ray at the specified time intervals.

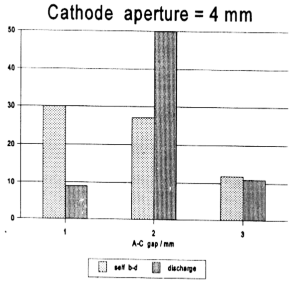

Fig. 4.7 : The total number of discharges with emission and total number of self-breakdowns for interelectrode spacings of 1, 2 and 3 mm.

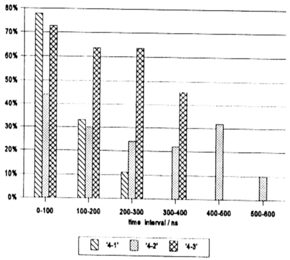

Fig. 4.8 : Percentage of discharges that have emission of x-ray at the specified time intervals.

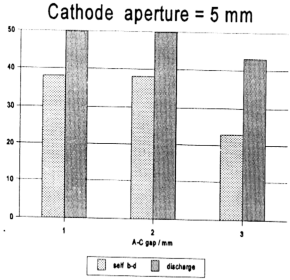

Fig. 4.9 : The total number of discharges with emission and total number of self-breakdowns for interelectrode spacings of 1, 2 and 3 mm.

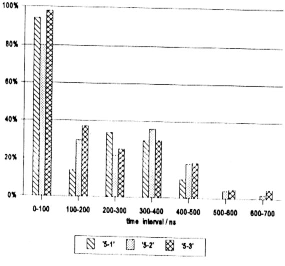

Fig. 4.10 : Percentage of discharges that have emission of x-ray at the specified time intervals.

variation in the characteristics of the discharges except that the discharges cannot be initiated for setup 5-3 after 40 - 50 discharges.

4.4 : Discussion and summary

The electrodes are eroded due to the discharges. This can be seen from the increase in the cathode aperture and the interelectrode spacing. For the anode, a crater is formed on the tip, which is due to the repeated bombardment by the electron beam. The anode has a polished surface displaced more to one side. Since the anode is attached to the capacitor using a threaded design, the axis of the anode is not aligned with the axis of the cathode. However, from the crater formed and the polished surface on the anode, it shows that the electron beam goes along the axis of the cathode aperture. The self-centring of the electron beam are due to the electric field distribution of the electrode geometry. The electric field distribution has been computed *[Ong, 1992]* and is as shown in Fig. 4.11.

The experiments with various A-C gaps and cathode apertures are used to determine the electrode configuration that can hold the charging voltage and be initiated to breakdown to produce intense emission of plasma x-rays reproducibly. If Paschen's law is applied, the system should be able to hold the charging voltage better when the distance between the electrodes is decreased. However, due to the geometry which is nonplanar and the constricted cathode opening, this is not observed. Paschen's law was based on parallel plate geometry and for this geometry, the distance between the electrodes are the same. Also, the electric field

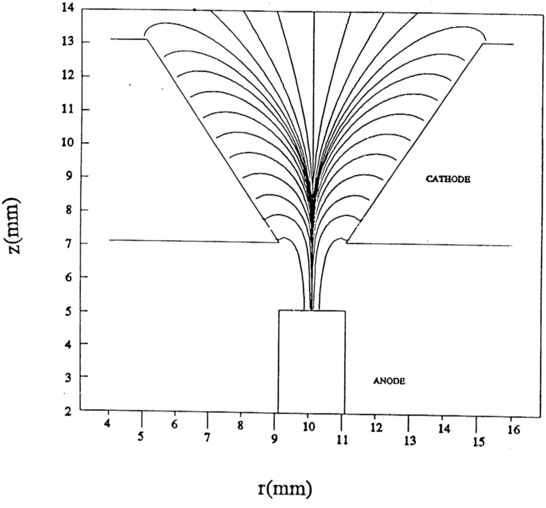

Fig. 4.11 : The electric field lines for the vacuum spark system with anode voltage of 20 kV.

is uniform between the electrodes. In the present setup, the distances between the electrodes are not the same due to the geometry of the electrodes. This would give different values of *pd* and also a nonuniform electric field. Probably, these factors influence the breakdown properties and cause the self-breakdowns to occur.

There are also configurations that do not breakdown after a few discharges even when initiated. Probably, deterioration or damage processes to relatively closely spaced electrodes may produce configurations that are unknown beforehand. This might be the reason some configurations can breakdown in the earlier stages but not after a few discharges. Another reason might be due to the pressure. It has been reported *[Favre et al., 1992]* that, the minimum pressure at which breakdown takes place is also reduced when the diameter of the aperture is increased. This might be a possible explanation for the present setup but it is not conclusive because the geometry used by Favre et al. is different.

From all the configurations tested, it is found that for inter-electrode spacing of 2 mm the plasma x-ray emission from all three cathode apertures is consistent. From these three setups (3-2, 4-2 and 5-2), the configuration with cathode aperture of 4 mm gives the best yield. Also, this setup is a good choice because it can last for a large number of discharges. As can be seen for setups 5-2 and 5-3, the x-ray emission is quite intense and consistent. Therefore, 4-2 would be a good choice because the erosion of the electrodes would not alter the yield very much.

Configurations that are not suitable had either many self-breakdowns, cannot breakdown at all or cannot breakdown after a few discharges. Even some setups with consistent output are not suitable because the intensity of emission is low.

In the experiments carried out using the 4-2 setup, it is found that the system can be evacuated and charged-up faster after 10 - 20 discharges. Also, 60 - 65 % of the discharges have medium to high intensity x-ray emission with most of the emission occurring at 300-500 ns after the breakdown.

From the series of experiments carried out, it seems that the best electrode configuration is that with a cathode aperture of 4 mm and an inter-electrode spacing of 2 mm. For this setup, discharge can be initiated consistently with strong x-ray emission at or near the current maximum.