TESTS WITH A MULTIDIPOLE ION SOURCE ON THE CERN 500-keV EXPERIMENTAL PRE-ACCELERATOR

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Summary

A pulsed, multidipole ion source (bucket ion source), similar to dc ones used in the fusion field for neutral injection, has been built and tested on an experimental pre-accelerator. Preliminary results are given and a comparison is made with the usual duoplasmatron ion source. Because of its very low noise, simple design, smaller number of variable parameters and lower power consumption, the eventual installation in the preinjector of the new CERN 50-MeV linac looks attractive.

Introduction

The CERN duoplasmatron[1] ion sources have proved to be reliable and efficient sources of protons for the CERN accelerator complex. However, the "grass", or noise inherent in the beam pulse when the source is being operated at high currents, is giving rise to concern. This noise can only be eliminated at the cost of inferior beam quality and is believed to arise inside the expansion cup.

A multipole confinement device[2] essentially has a quiet plasma contained in a region of practically zero magnetic field. Ion sources based on this principle have been built[3] generally as direct current or long pulse sources for use in nuclear fusion experiments.

For accelerator use, the multidipole source (or MDS) seemed worthy of investigation, in view of its reported low noise properties and apparent small emittance.[4] A short test on a dc source at Culham Laboratory,[4] indicated that it might be possible to operate with pulses as short as 100 μs with fast rise-times.

Description of the source

When deciding to build a prototype MDS source, the first limiting parameter was the space available inside the preinjector columns, especially as it was not intended to use a special extractor electrode. The inside diameter of the anode of the 750-keV column of the new linac; therefore, limited the maximum outside diameter of the source to 210 mm. Figure 1 shows the source as built in its water-cooled version. Figure 2 is a cross-section of the source also showing electrical connections. An air-cooled source had a welded stainless steel plasma chamber but the water-cooled source has an aluminum alloy body. Most of the data and results presented here refer to the air-cooled source.

The space limitation and available magnets led to the adoption of the full line cusp geometry proposed by Leung et al.,[5] and considered by them as the best one. The plasma vessel is 110 mm diameter by 100 mm deep and 1.3 mm thick, with a port in one end for the cathode. Twelve rows of rare earth-cobalt plastic magnets produce the multipole field and are continued radially over the backplate to the cathode hole. These magnets give a maximum field of about 1.5 kG at the walls and a region of about 50 mm diameter at the center with less than 10 G.

As there was no experience with bright thermionic emitters and as there were power supplies and components available, the standard oxide coated duoplasmatron cathode[6] was used in the source. At its working temperature, the cathode dissipates about 150 W and the magnets seem to stay below 100° C. It is doubtful if a bright thermionic emitter could be used in the air-cooled source.

The front plate of the source is an insulated stainless steel disc carrying a titanium (TA6V) alloy nose with a 14 mm extraction hole and Pierce angle geometry. Titanium was used to ensure that the high voltage performance of the preinjector would not be deteriorated. This front plate can be biased relative to the source body.

In view of the geometry of the source, the cathode can see down the high voltage column. After considerable problems with high voltage stability and radiation, a small floating shield of titanium was mounted in front of the cathode, and this seems to have given greater stability without apparent beam loss.

Arc characteristics

Before the source was mounted in the experimental preinjector, the arc characteristics were studied in a grounded test rig. A standard CERN arc power supply,[7] which consists of a thyristor discharged 10 Ω delay line pulser with about 5 Ω of series resistance, was used.

Initially the source was difficult to fire and high arc voltages were measured (∿150 V), but after some hours the arc voltage dropped to around a normal value of 80 V. It is not yet known if this phenomena is inherent in the source, but there are indications that these problems may have been due to the state of the cathode, or to surface phenomena in the arc chamber. These phenomena have not been seen in the water-cooled source.

The arc voltage and current were insensitive to the negative bias on the front plate down to about -40 V, corresponding to the potential of the plate if it was allowed to float. Grounding the front plate drastically increased the arc current rise-time. Normally the plate was held at -100 V.

Once the arc became normal, it was found to be very sensitive to cathode temperature. Acceptable operation could only be obtained in a temperature band of about 60° C around the nominal cathode temperature of about 800° C (i.e., approximately ±3 A on a filament current of 50 A). The cathode showed less sensitivity at higher arc currents. Figure 4 shows oscilloscope pictures of the arc voltage and current for the conditions of too cold, normal and too hot operation. Again, there are indications that these effects may be due to the particular cathode used in these tests.

With high currents ($\sim$100 A) and low gas flows (2-5 cc/min), the arc firing delay was observed to increase in the air-cooled stainless steel source; delays of several tens of milliseconds could be produced. This effect was not observed with the water-cooled aluminium source.

Measurements of the radial current density distributions obtained using standard Langmuir probe techniques in the water-cooled source are shown in Fig. 3. The uniformity of the current density across the back of the exit hole is quite apparent.

Tests in the experimental preinjector

It quickly became obvious during tests in the experimental preinjector, that the extracted current and beam quality were very dependent upon source position. By trial-and-error techniques, it was found that the best beam conditions, as defined by the cleanest pulse in the first current transformer and the best transmission through the first triplet, were obtained when the position of the hole in the nose relative to the preinjector anode roughly corresponded to that found in the past for the duoplasmatron. If the source was too far forward, little current was extracted, whereas if it was too far back, a large current could be obtained but with very poor transmission and poor voltage holding of the preinjector column.

With the source positioned as near as possible to the optimum, it was found that the beam pulse reflected certain characteristics of the arc voltage, which enabled the source filament current to be adjusted to its optimum value. Figure 4 shows the beam pulse as measured in the first current transformer for the conditions of too cold, normal and too hot cathode.

The almost complete absence of noise on the beam pulse during normal operating conditions (Fig. 4b) can be clearly seen and should be compared with a comparable beam from a duoplasmatron (Fig. 5).

Currents obtained from the MDS were roughly linear with respect to arc current. Typical values were 190 mA for 60 A arc, to 420 mA for 100 A arc current and 10 cc/minute of hydrogen. The source output saturated above about 110 A arc. Beam composition was not measured.

It was found that the source parameters for a given beam remained stable from day-to-day and could also be reproduced, with a short running in period, after a cold start.

Manual emittance measurements suggested that it would be worthwhile to perform a test run on the new linac.

Measurements on the new linac

After installation in the 750-keV preinjector of the new linac and proper source parameter set-up, the MDS again showed little noise and extremely good stability. Figure 6 shows a comparison of the MDS and duoplasmatron beam profile measurements in the LEBT, made with a movable slit and a beam transformer behind it. In the former, even several scans did not show any variations.

The emittance measured in EM2 (Fig. 7) did not seem very encouraging, but it is highly probable that there was considerable contamination from H_2^+, H_3^+ and perhaps N^+ or O^+, especially in view of the high losses in the beam transformer readings between IM4 and IM5. Typical values for 102 A arc and 10.2 cc/min hydrogen were:

IM2 (after column)	325 mA
IM4 (before buncher)	301 mA
IM5 (after buncher)	163 mA
IM6 (into Tank 1)	163 mA
IM9 (out of Tank 3)	140 mA

The emittance measured in EM3 (after the buncher) was much more reasonable (Fig. 8).

The maximum current obtained at 50 MeV was 140 mA compared to a maximum of 160 mA normally obtained with the standard duoplasmatron. Emittance measurements at 50 MeV indicate that the beam quality was certainly not worse, but was probably better than that obtained from the duoplasmatron source. There is still room for improvement in the linac settings, but this was not tried because of lack of time.

Conclusions

The object to build a pulsed MDS has been achieved and initial tests indicate that all its promises can be fulfilled.[8] However, further fundamental investigations are needed to understand some of the early problems and more operational experience will be needed before it can be envisaged using this source operationally for the CERN accelerator complex.

Acknowledgements

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References

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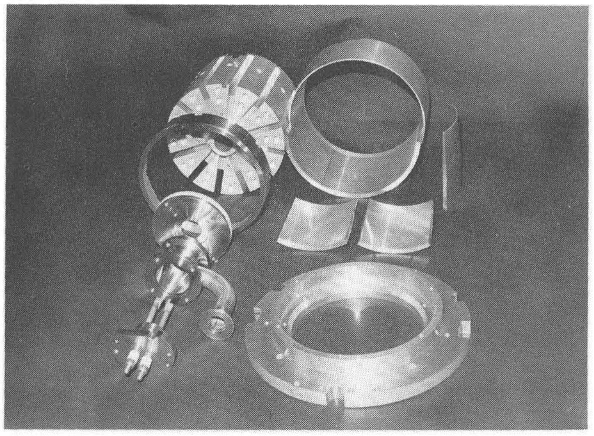


Fig. 1 Prototype MDS

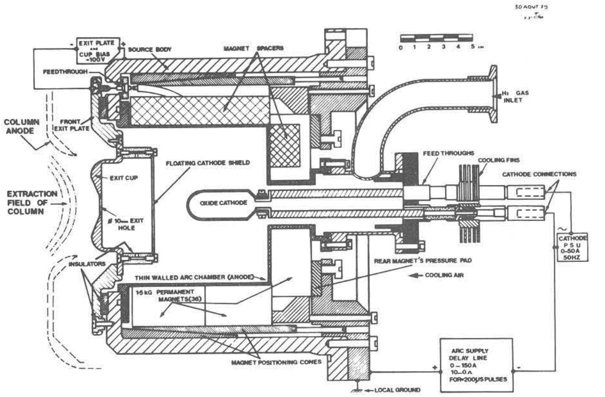


Fig. 2 MDS1 cross section and electrical schema

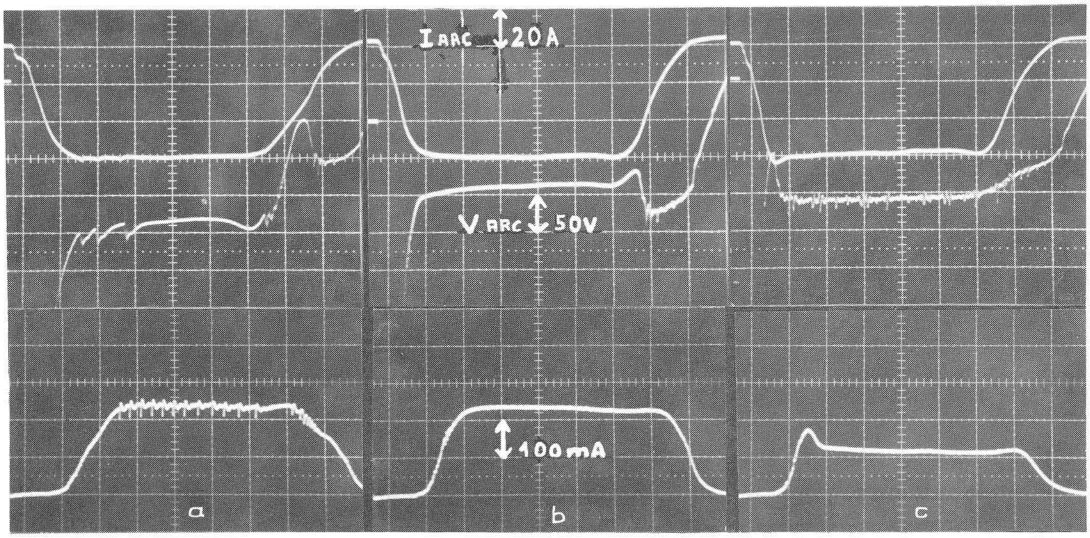


Fig. 4 Arc and beam characteristics for (a) too cold, (b) normal, (c) too hot cathode – upper-arc, lower-beam pulse

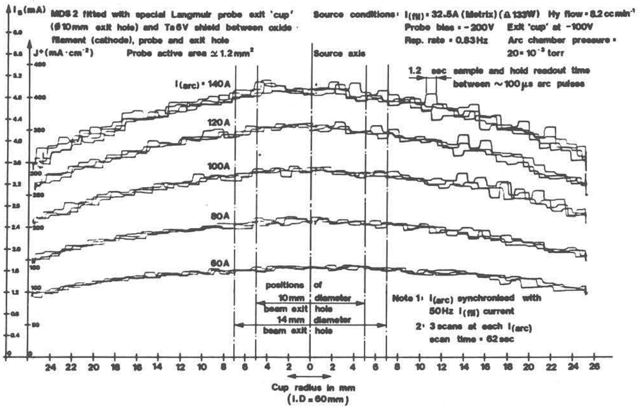


Fig. 3 Plasma + VE ion current $1_{(s)}$ and current density (J^{+}) variation across 'cup' with $1_{(arc)}$

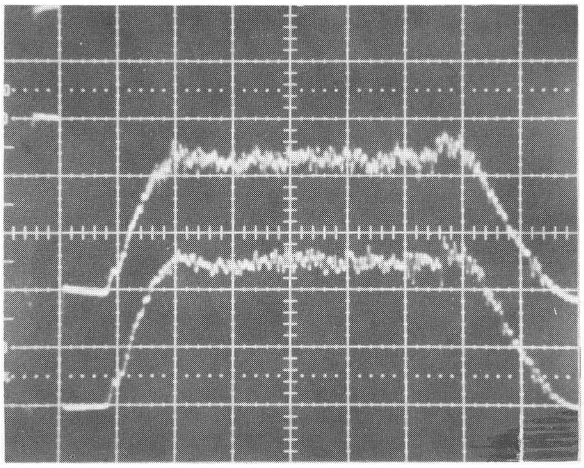
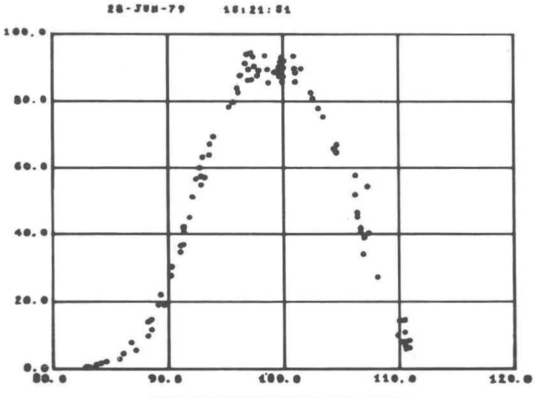


Fig. 5 Typical duoplasmatron output 100 mA/div.



DUOPLASMATRON HORIZONTAL BEAM PROFILE

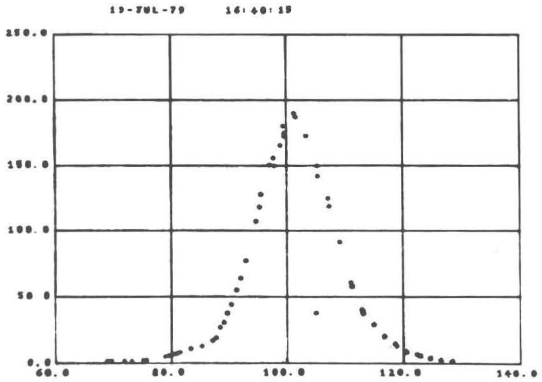
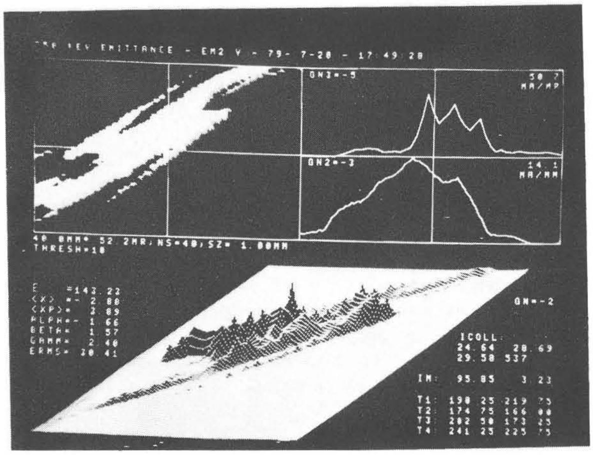


Fig. 6 Multidipole ion source horizontal beam profile



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                             29.58  537
                           IM:  95.85   3.23
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                           T3:  202 50 173 25
                           T4:  241 25 225 75
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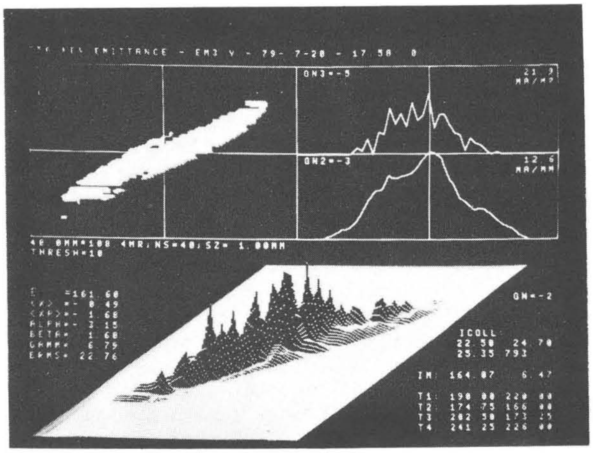
Fig. 7 Emittance in EM2



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                             25.35  793
                           IM: 164.07   6.47
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                           T2:  174 75 166 00
                           T3:  202 50 173 25
                           T4:  241 25 226 00
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Fig. 8 Emittance in EM3