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AGS DIVISION TECHNICAL NOTE*

No. 54

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September 27, 1968

A DUOPLASMATRON WITH OSCILLATING ELECTRONS

History

The standard duoplasmatron (see Fig. 1) has a hot cathode, intermediate electrode and anode. The discharge is constricted (by the shape of the intermediate electrode) into a small area in front of the anode aperture and a short non-uniform magnetic stray field between the intermediate electrode and anode. The current density in front of the aperture is large ($\sim$ 1 A/mm^2).

There are two plasma concentrations; one close to the cathode (cathode plasma) and one concentrated before the anode (anode plasma). The cathode plasma inject a beam of electrons with enough energy to ionize the gas molecules in the anode region, creating a potential increase (10 - 30 V) close to the anode aperture. The ions are then repulsed through the anode aperture together with those electrons which have enough energy to pass the deceleration region. The expansion cup is, therefore, filled up with directed ions and electrons.

With our standard duoplasmatron, we can obtain 250 to 300 mA beam output with a 1/2" diameter expansion cup (Ref. 1, 1966). Connecting this source to our high gradient accelerating tube, we have the situation as it is shown in Fig. 2.

*This note is meant to be a guide line.

This configuration has accelerated a maximum beam current of 200 mA with a gaussian type of density distribution (Ref. 2, 1967). Larger beam currents can be extracted but not accelerated due to beam losses in the tube and in the focusing magnets. The beam optics of the accelerating tube is based on an ion density of 100 mA/cm^2 and not 200 mA/cm^2. The limitation arises from the defocusing influence of the space charge mainly in the extractor region.

An apparent solution is reducing the density by increasing the expansion cup diameter and extractor aperture. The source capacity (determined by the discharge current) seems to be large enough to fill up the increased volume of the enlarged plasma cup. Nevertheless, the column output could not be increased.

A possible explanation is that for larger beam currents the plasma cup cannot be filled up uniformly; a larger density in the center of the beam shapes the ion emitter as shown in Fig. 3. The emitter configuration is determined by the plasma-pressure, extractor field, electrode geometry and stray magnetic field. Uniform density distribution is, therefore, important. It might be obtained by biasing the inner wall of the expansion chamber as it is suggested by Vienet and Faure (Ref. 3, 1967). The idea is that a slightly negative voltage keeps the electrons in the beam, neutralizing some of the space charge defocusing. Their results does not seem to be reproducible for 100 mA beam currents (private communication from Vienet, 1968). For larger currents (> 100 mA) this solution might be even more difficult to realize.

A more promising approach to a uniform and yet dense ion distribution seems to be the sources with double contraction of the discharge (duoplasmatron) and oscillating electrons in the anode plasma (Demirkhanov,

et al., Ref. 4, 1963). Such a duoplasmatron allows reduction of the gas pressure ($\sim 10^{-2}$ mmHg instead of the 1 mm) allowing for a large anode aperture (5 mm = .2" instead of 1 mm = .040"). The current from such a source seems to be hundreds of milliamperes, but what seems to me more important is the larger aperture that allows for a better development of a more uniform ion emitting surface inside the expansion chamber. The current density of reflector aperture is now much lower $\sim$ .1 A/cm^2.

Modified Duoplasmatron Hydrogen Source

A standard duoplasmatron has been extended with a reflecting electrode. Figure 4 shows the basic configuration. The electrons from the cathode plasma are injected into the anode region, as it is the case with the standard duoplasmatron. The anode is now followed by an electrode with negative potential with respect to the anode; therefore, the electrons oscillate between the reflector and intermediate electrode, constricted by the relatively long magnetic field. The increased distance between the electrodes, as well as the oscillation of the arc electrons, is required to compensate for the lower gas pressure ($N_i = N_o \sigma_i \ell$). The gas pressure can be, therefore, as low as 10^{-2} mmHg and electrode apertures larger than 5 mm (.2"). It will be difficult to predict the optimum geometry and distances between the electrodes for our requirements. We will, therefore, start with roughly the distances between the electrodes as used by Demirkhanov (see Fig. 4), maintain our intermediate electrode geometry, add a reflecting electrode and increase all apertures to ϕ 5 mm (.2").

In addition, the source body has to be electrically isolated to provide a negative voltage to the reflector (which is the anode in the standard duoplasmatron).

The diameter of the expansion chamber for a 300 mA total current should be 2 cm for a current density of 100 mA/cm^2, which is the designed density for the accelerating tube. For an extractor voltage at 50 kV, the Pierce geometry requires a distance between extractor and ion emitting surface of 25 cm = 1". The space charge limited current is therefore:

$$J = 5.6 \times 10^{-8} \frac{V^{3/2}}{x^2} = .1 \text{ A/cm}^2 \text{ with } V = 50{,}000 \text{ volts and } x = 2.5 \text{ cm.}$$

The depth of the expansion chamber should be as long as possible to keep the emittance small, but not too long because we might lose too much current against the walls of the cup. Let us start with 2 cm = .8". The maximum magnetic field should be in the order of 1000 gauss.

A stopper behind the cathode might be necessary to stop the well collimated electron beam that can pass the intermediate electrode. Experience will show if this and (or) other modifications are necessary.

The "snout" of the reflector might be too flat for proper guidance of the ions into the expansion cup.

Some Additional Remarks

a) One has to be aware that the practical behavior of this source will be rather different from the standard source. For instance, a too high gas pressure will extinguish the discharge.

b) The aperture of the intermediate electrode might be too small. The losses can be observed on the amp-meter connected with the intermediate electrode. Also the anode and reflector current will give information about the formation of the anode plasma.

c) The gas inlet in the anode plasma will be more effective than with the gas inlet in the cathode region.

d) If the results are positive, it should be easy to extract the 300 mA beam directly with the 150 kV first electrode in the short column without extractor. This simplifies the total structure considerably.

Expected Parameters of the Slightly Modified Demirkhanov Source

Ion beam current at extraction voltage of 50 kV	300 mA
Emittance (area/π)	5 cm-mrad
Gas pressure in source	$< 5\text{-}10^{-2}$ mm
Gas pressure around extractor	$< 10^{-5}$ mmHg
Arc voltage	< 250 volts
Arc current	< 20 amps
Source magnetic field	< 1000 gauss

The dimensions of the source (see Fig. 4)

Literature

Ref. 1 - Th.J.M. Sluyters-1, "Brookhaven's Recent Pre-accelerator Progress," AGS Internal Report, 1966.

Ref. 2 - Th.J.M. Sluyters, V. Kovarik, "Large Brightness Beams Up to 200 mA in a 750 kV High Gradient Preinjector," AGS Division 67-6, 1967.

Ref. 3 - J. Faure, "The New Saturne Injector Status Report on the 750 keV Preinjector," Linear Accelerator Conference, Brookhaven, 1968.

Ref. 4 - P.A. Demirkhanov, et al., "High Current Injector of Hydrogen Ions," Dubna Conference, Moscow, 1963.

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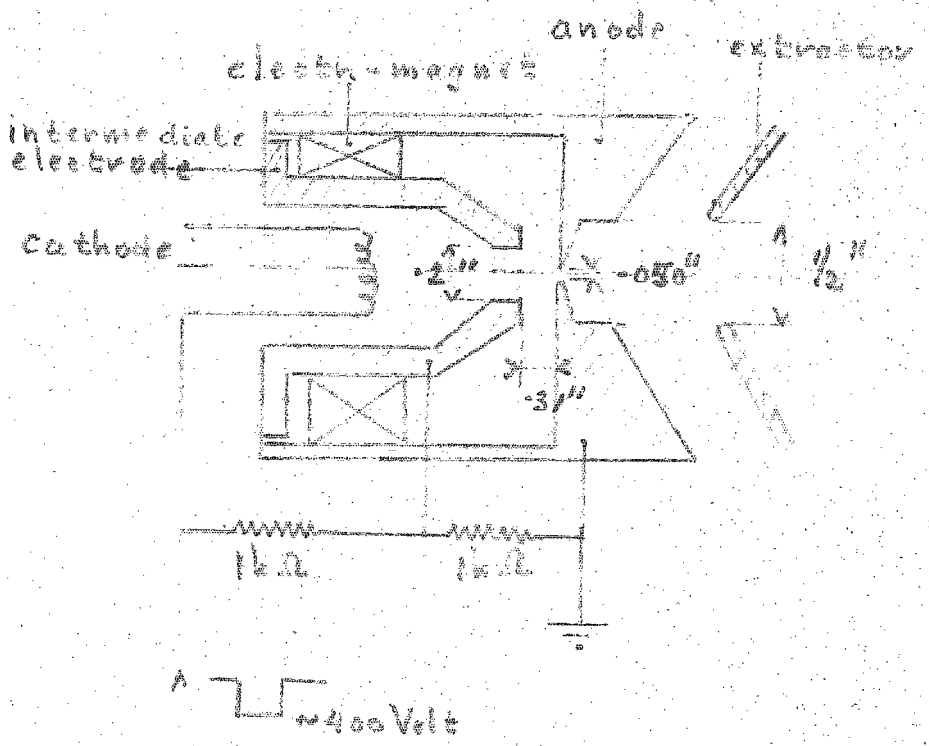

Figure 1 Standard duoplasmatron

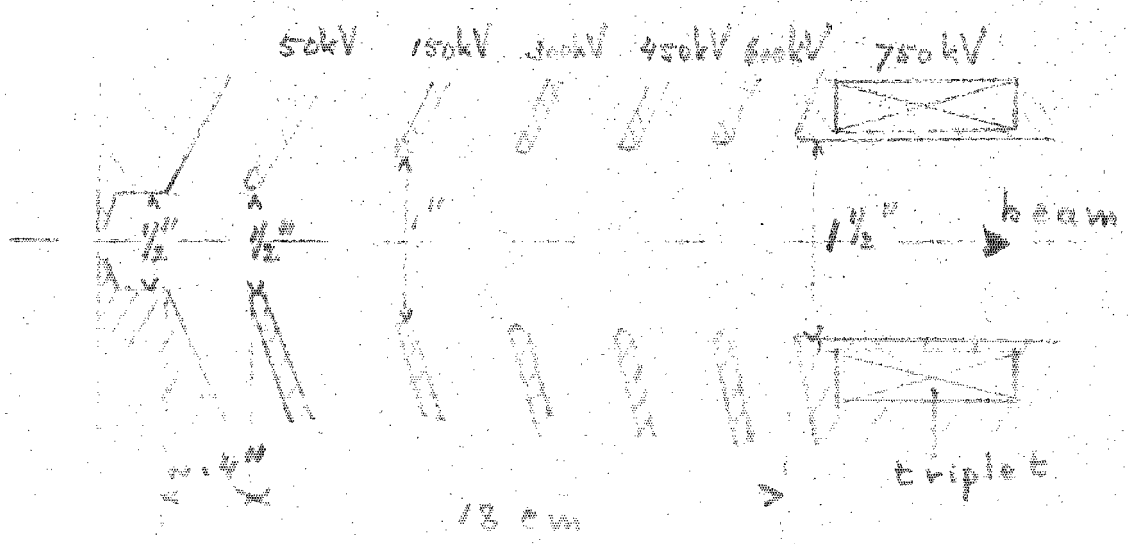

Fig. 2 Pierce shaped accelerating column for 100 mA/cm².

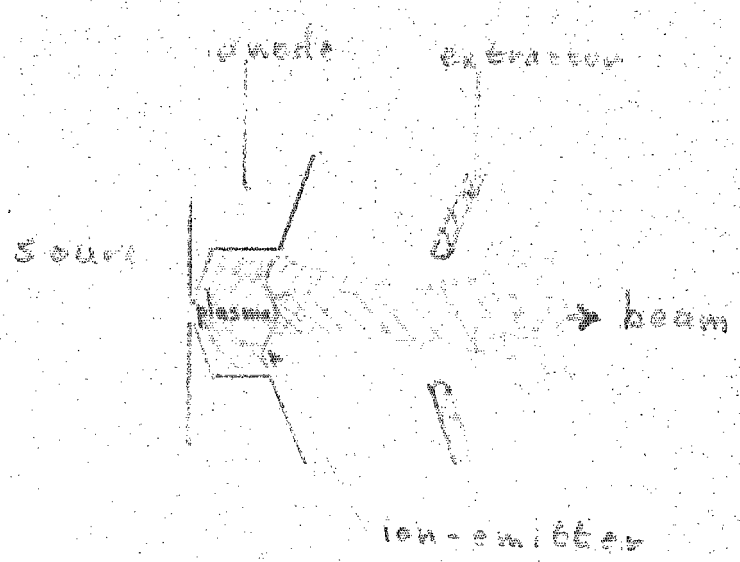

Figure 3 Distortion of ion emitter.

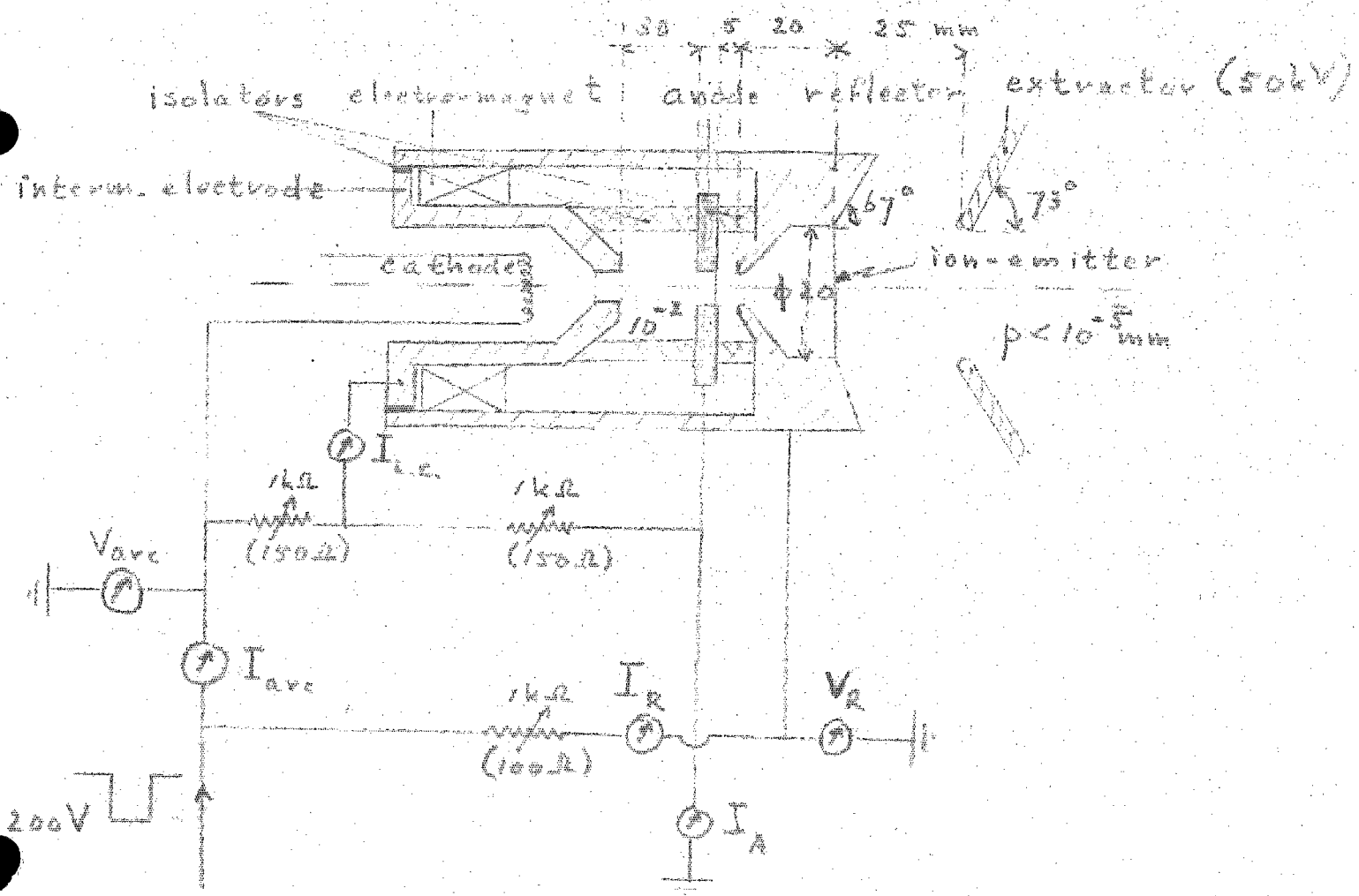

Figure 4 Initial characteristics of duoplasmatron with oscillating electrons.