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ELECTRICAL PROBE MEASUREMENTS IN LOW AND HIGH PRESSURE DISCHARGES

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ABSTRACT

The construction of an apparatus for automatic determination of electron velocity distributions is described, whereafter measurements of electron energy distributions before and after a stationary plasma sheath in a low pressure mercury discharge are presented. The sheath appears at a constriction of the discharge tube. The measurements have been made with a spheric probe, using the second-derivative method, and the results show that the energy distribution on the anode side of the sheath is a sum of a thermal population and an accelerated distribution. Near the sheath the accelerated electrons suffice to carry the discharge current, but far from it the current must be carried by an anisotropy in the thermal part of the distribution function. A comparison is made with calculated distributions. The cross-sections for electron-neutral and Coulomb collisions are not sufficient to account for the damping of the accelerated population, suggesting the presence of a plasma instability. In order to study the distribution function of the axial velocity component, preliminary measurements of the first derivative of the current to a plane probe have been made. Such measurements yield information about the anisotropy and the current transport, and may perhaps shed some light on the phenomenon of current limitation.

Some measurements on a TIG welding arc are also described. Emitting probes have been used to determine the potential distribution in the arc. In addition, measurements of the current-voltage characteristic of the arc, the current density and the pressure at the anode have been made. Gas streaming velocities along the axis have been calculated.

The following papers by Dag Andersson are included in the thesis:

A.1. Report 69-06, Dept. of Electron Phys., Royal Inst. of Technology, Stockholm, Sweden: Apparat för automatisk uppmätning av elektroners hastighetsfördelning (Apparatus for automatical determination of electron velocity distributions). In Swedish only.

2. Report 70-31, Dept. of Electron Phys., Royal Inst. of Technology, Stockholm, Sweden: Measurements of electron velocity distribution functions in front of and behind a plasma sheath.

3. Report TRITA-EPP-76-10, Dept. of Electron Phys., Royal Inst. of Technology, Stockholm, Sweden: Measurements of electron energy distributions in front of and behind a stationary plasma sheath.

4. Report 76-102, Dept, of Electron Phys., Royal Inst. of Technology, Stockholm, Sweden: The first derivative method - a probe method which seems to have been overlooked.

B.5. Report TRITA-EPP-74-05, Dept, of Electron Phys., Royal Inst. of Technology, Stockholm, Sweden: Measurements on a TIG welding arc.

Papers 1-4 deal with probe measurements in low pressure mercury arcs, whereas 5 deals with measurements in an argon arc at atmospheric pressure.

A. Probe measurements in low pressure mercury arcs

Electrostatic sheaths and double-peaked electron velocity distributions have been discussed in connection with space physics (Block 1972) and also detected in laboratory discharges by e.g. Crawford and Freeston (1963). It is important that stationary sheaths and normal positive columns are studied at higher current densities as this may cast light on the phenomenon of current limitation and non-stationary sheaths (discussed by e.g. Carlqvist 1972, Babić and Torvén 1974 and Torvén and Babić 1975, 1976). The electron velocity distribution is of great importance in this context.

In paper 1 an elementary presentation of electron velocity distributions is given, whereafter measurements of such distributions by means of electrical probes are discussed. Some of these methods date back to Langmuir (Suits 1961) and Druyvesteyn (1930). If the velocity distribution is isotropic, it can be determined from the second derivative of the current to e.g. a plane probe with respect to the potential. If the velocity distribution is anisotropic, the second-derivative method applied to a spheric probe gives the energy distribution if the sheath around the probe is thin in comparison with the probe. Alternatively, the distribution of a velocity component can be obtained from the first derivative of the current to a plane probe.

The derivatives are determined by superimposing a small 1 kHz voltage on the probe potential. Due to the nonlinearity of the probe characteristic, the resulting current contains upper harmonics. The second harmonic (2 kHz) is proportional to the second derivative of the current, whereas the first harmonic is proportional to the first derivative.

Finally the construction of the apparatus is described and some examples of measurements are given.

In paper 2 the method and apparatus are reviewed and some special problems discussed, e.g. the determination of the plasma potential, distortion and calibration, whereupon measurements in a mercury discharge are described. In this discharge a stationary sheath appears at a constriction of the tube where the diameter is decreased from 34 mm to 11 mm. The measured energy distribution looks rather maxwellian before the sheath (although it must be anisotropic), but after the sheath it is a sum of a maxwellian population and a population which has been accelerated through the sheath. The latter is further accelerated somewhat in the narrow tube due to the electric field in the plasma and also damped.

The mercury pressure and the current through the sheath have been varied and the measurements have been repeated at different points along the axis of the tube. Diagrams of potential distribution and electron density are also supplied.

Finally some simple calculations are presented of how different distributions are changed when they are accelerated through a plane potential step. When these calculated distributions are compared with the measured ones, it is obvious that the density of the accelerated electrons is higher in the latter, suggesting that the hemispherical shape of the sheath and the reflecting walls are of importance.

In paper 3 a selection is made of the distribution functions in paper 2 and the electron densities are somewhat modified. The quantity $n_e e\bar{v}$, where n_e = electron density, e = electronic charge and $\bar{v}$ = average value of the magnitude of velocity, is calculated both for the whole distributions and for the accelerated populations separately. When this quantity is compared with the discharge current density, some conclusions can be drawn about the anisotropy of the distribution functions. It turns out that the distribution before the sheath must be strongly anisotropic at the high current densities in this discharge tube, in contrast to the maxwellian distributions which are applicable at low current densities (Crawford et al. 1963). Immediately after the sheath the accelerated electrons suffice to carry the discharge current, but further toward the anode the current must be carried by an anisotropy in the thermal part of the distribution function.

Some simplified calculations of accelerated distributions, where the influence of the hemispheric shape of the sheath and the reflecting walls is taken into account, are presented and compared with the measured distributions.

The damping of the accelerated population along the tube is compared with the cross-sections for electron-neutral and Coulomb collisions. It turns out that these are not sufficient to account for the damping, suggesting that a plasma instability mass be present.

Paper 4, being more preliminary, deals with the method of determining the distribution function of a velocity component from the first derivative of the current to a plane probe, a method which has already been mentioned in paper 1. Preliminary measurements in a mercury discharge are described, and it is concluded that this method may be of value in studying current transport in a positive column and the phenomenon of current limitation (Torvén and Babić 1976) which has not yet been satisfactorily explained. New measurements of this kind, together with high frequency measurements, are planned in e.g. a plasma confined in a magnetic field.

B. Measurements on a welding arc

The importance of welding technology is obvious, and there is a need for better understanding of the physical processes in welding arcs. In collaboration with AGA and ESAB research has been done in this field at our department. In paper 5 measurements on a TIG welding arc (TIG = Tungsten Inert Gas) in argon between a pointed tungsten cathode and a water cooled copper anode are described. As no reasonably simple theory exists for the use of ordinary Langmuir probes in such a plasma (Swift and Schwar 1970), emitting probes have been used to study the potential distribution in the arc. The probe characteristic is in this case determined with and without electron emission; the characteristics converge at the plasma potential. In addition, the current-voltage characteristic of the arc, the current density at the anode, the anode fall, the stagnation pressure at the anode and the gas streaming velocity along the axis of the arc have been determined.

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ELECTRICAL PROBE MEASUREMENTS IN LOW AND HIGH PRESSURE DISCHARGES (Thesis)

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Key words Low pressure arc, Sheath, Double layer, Electrical probe, Druyvesteyn's method, Second-derivative method, Energy distribution, Velocity distribution, TIG welding arc