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A Trochoidal Monochromator to Measure Electron Beam Energy Distribution in Axial Magnetic Field

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Abstract: The trochoidal monochromator is commonly used to produce a monoenergetic electron beam in an axial magnetic field. By adding a retarding electric field system at the entrance, and a Faraday cup at the exit of the monochromator, such a dispersive device can be used to measure the energy distribution of an electron beam. An experimental set-up composed of an electron gun and the trochoidal analyser is described. A monoenergetic cold beam is produced and analysed in an axial magnetic field. This set-up will be used in a travelling wave tube in order to study wave particle interactions.

A $\mathbf{E} \times \mathbf{B}$ energy analyser for electrons has been used by W. L. Barr and W. A. Perkins[1] to measure energy distribution functions of the "hot electron plasma" produced in a compression mirror machine. This analyser works with electron energies up to 20 keV with 1,2 kG. The use of trochoidal motion of electrons in crossed electric and magnetic field for energy dispersion was first reported by Stamatovic and Shulz[2]. The trochoidal monochromator has been used to prepare monoenergetic electron beams for electron transmission and dissociative attachment studies. Recently, M. Allan[3] uses a trochoidal analyser both to prepare a beam of monoenergetic electron and to analyse the energy of the scattered electrons. With two analysers in series and several attempts to overcome severe background problems, he presented a 36 meV resolution for this instrument. The analyser described here can determine the distribution function of a cold or warm beam ranging in 10-150 eV with a constant resolution of the order of 0,5 eV.

1. Principle of the trochoidal analyser

The trochoidal analyser works on the principle that charged particles undergo a lateral drift when passing through a region in which an electric field $\mathbf{E}$ is perpendicular to a magnetic field $\mathbf{B}$ (figure 1). Although the drift velocity is the same for all electrons, the total displacement is greater for slower electrons (which spend more time in the drift region).

Figure1: Principle of the trochoidal analyser.

The energy w_p of an electron that can escape the analyser is expressed in eV by

$$w_p = \frac{1}{2\eta} \left(\frac{L}{D} \frac{E}{B} \right)^2 \quad (1),$$

where $\eta=e/m$, L is the length of the deflector plates (defining the drift region) and D the aperture offset of the exit electrode.

Because of the diameter of the apertures defining the beam in the drift region, a geometrical resolution is obtained. An additional energy spread results from the transverse electric field. Two electrons located on both sides of the entrance aperture along the electric field feel a potential difference. The maximum potential drop across the electron beam is $E S_1$ where S_1 is the diameter of the entrance aperture. The energy resolution of the analyser, expressed in eV, is consequently the sum of two terms

$$\Delta w_{th} = 2 \frac{\Delta D}{D} w_p + \frac{S_1}{a} \Delta V \quad (2),$$

with ΔD the sum of the aperture diameters of the entrance and exit electrodes, and ΔV the potential difference on the deflective plates separated by a distance a .

The electron energy distribution is determined by retarding the electron beam by means of entrance electrodes and selecting electrons having passage energy w_p by means of the potential difference on the deflector plates. For a given ΔV , the resolution is constant (see figure 1).

2. Description of the apparatus

The mechanical structure of the electron-optical system of the present instrument follows closely the original design of a trochoidal monochromator presented by Stamatovic and Schulz[3]. A stack of circular molybdenum plates with apertures and deflector plates kept in alignment by precision ruby balls is squeezed between end plates by means of three threaded rods with nuts.

The retarding system consists of three disks A1, A2 and A3 which are kept at a negative potential with respect to ground. A3 serves as the entrance electrode into the crossed field region. The deflector plates AD1 and AD2 are made by machining a cylinder of the same diameter as the electrode disks and by cutting it in half along its axis. The off-center aperture on the exit electrode A4 is used both for alignment of the magnetic field and to reduce the number of "fast" electrons which may produce undesirable secondary electrons in the drift region. Most of the electrons that have not been scattered are collected by electrode A5. The alignment of the magnetic field is performed by measurement of the maximum beam current on electrode A5 with electric field switched off. Finally, scattered electrons are collected in a Faraday cup located behind the off axis aperture in A5 and the current measured by means of a pico-ampemeter.

	Electrodes	Size in mm	
Plate diameter	A1 à A5	16.0	
Plate thickness		1.0	
Ruby ball diameter		1.5	
Spacing between plates		1.0	
Length of the deflecting plates		19.0	
Gap between deflecting plates	A4, A5	3.2	
Aperture offset		3.2	
Aperture diameter		A1, A2	1.0
		A3, A4	0.5
	A5	0.8	

Table 1: Characteristics plates and aperture dimensions.

The influence of reflected electrons on the energy distribution is reduced by plating all pieces of the electron gun and analyser with colloidal graphite in isopropanol.

The electron source is a hairpin shaped thoria-coated tungsten filament. The tip of the pin is located across the 1 millimeter diameter aperture of a Pierce electrode to reduce the velocity spread induced by the potential difference in the filament (estimated value approximately 0.4 eV). The special shape of the

Pierce electrode induces the formation of a parallel beam. Electrons are also radially confined by a strong magnetic field of 500 gauss during their propagation (figure 2).

Figure 2: Schematic diagram of the electric circuit.

Results have been obtained in a test vacuum seal (a few 10^{-8} torr). Electron gun and analyser are separated by 4 centimeters.

3. Experimental results

Distribution functions are obtained for different electron energies ranging in 10 - 150 eV with $B = 500$ gauss and fixed deflecting voltage $\Delta V = 0,5$ V (figure 3a). Curves are obtained on a X-Y recorder by plotting the current measured on the Faraday cup on the Y-axis as a function of the retarding potential on the X-axis. Peaks of a few nanoamperes are well located at the initial electron energy with a small shift corresponding to the potential drop between the emission point of the filament and the reference point of the accelerating voltage. This shift depends on the cathode current I_k (1 V for 100 μ A). We believe that no shift would be given with an oxide coated cathode electron gun. The resolution is mesured by the determination of the width at half-maximum of the measured distribution. 477 meV average resolution is obtained (with a standard deviation of 56 meV). Eq. (2) gives 78 meV.

Figure 3: a) Distribution functions for different electron energies into $B = 500$ gauss and fixed deflecting voltage $\Delta V = 0,5$ V. Current (in nA) measured on the Faraday cup plotted as a function of the retarding potential V_a (in Volt). b) Measured $\Delta w_{1/2}$ and theoretical $\Delta w_{th} + \Delta w_{nc}$ analyser resolution at $B = 500$ gauss for three different beam energies (o: 30 eV, +: 60 eV, *: 90 eV).

The points in Fig. 3b gives the experimental resolution as a function of the deflecting voltage for three electron energies, 30, 60 and 90 eV at $B = 500$ gauss defined by the full width at half-maximum $\Delta w_{1/2}$ of the measured distribution. The solid curve corresponds to the theoretical resolution, Δw_{th} given by Eq. (2), increased by the approximate value of natural width of the filament emission, Δw_{nc} (around 0,4 eV).

The measured value is always greater than theoretically predicted. Notice that $\Delta w_{1/2}$ should even be smaller than values obtained from Eq. (2), which correspond to the full width of the distribution.

Stamatovic and Shulz find from experiment that the ratio $\Delta w_{th}/\Delta w_{1/2}$ is 2,5-3,5. We believe that the difference between our experimental points and theoretical curve proceeds from the resolution of the three retarding lenses system. For high retarding potential, due to the shape of equipotential lines across the apertures, electron longitudinal energy may be transformed into transversal energy. However, the smaller aperture of electrode A3, as compared to A1 and A2 should select electrons which have not been scattered. Also, deflector plates reject electrons that are not on the axis.

Conclusion

Distribution functions of cold beams with energy ranging between 10-150 eV have been obtained with a resolution around 0,5 eV. This analyser is presently used in a four meters traveling wave tube with an oxide coated cathode electron gun and 500 gauss magnetic field to ensure beam confinement. A resolution of the order of 0,5 eV is sufficient to follow correctly the evolution of a cold or warm distribution function during the wave particle interaction. A controlled warm beam will be produced by passing the cold beam through a system of three closely spaced parallel grids[4]. This analyser will advantageously replace a classic retarding system used on a smaller traveling wave tube at San Diego[5]. Since a better time resolution is expected for pulsed beam experiment.

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