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A miniaturised, nested-cylindrical electrostatic analyser geometry for dual electron and ion, multi-energy measurements

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A B S T R A C T

The CATS (Cylindrical And Tiny Spectrometer) electrostatic optics geometry features multiple nested cylindrical analysers to simultaneously measure multiple energies of electron and multiple energies of ion in a configuration that is targeted at miniaturisation and MEMS fabrication. In the prototyped model, two configurations of cylindrical analyser were used, featuring terminating side-plates that caused particle trajectories to either converge (C type) or diverge (D type) in the axial direction. Simulations show how these different electrode configurations affect the particle focussing and instrument parameters; C-type providing greater throughputs but D-type providing higher resolving powers. The simulations were additionally used to investigate unexpected plate spacing variations in the as-built model, revealing that the *k*-factors are most sensitive to the width of the inter-electrode spacing at its narrowest point.

1. Introduction

In many fields of research, from space science to the analysis of surfaces, electrostatic analysers are used to measure the energies, and sometimes the masses, of electrons and ions (of a few eV to a few tens keV) by deflecting and focussing them with electrodes. A myriad of electrode designs exist to accomplish this, each optimised towards specific particle study requirements and environment restrictions. For many applications, the miniaturisation of electrodes is desirable, and so a number of MEMS (Micro-Electro Mechanical Systems) based devices have been developed [1–3].

Some applications benefit from the simultaneous measurement of multiple energies of particle [4], and many space plasma measurements require both electron and (positive) ion data and so use two, oppositely configured analysers [5,6].

To achieve multiple measurements in a smaller sized package, curved plate electro-static analysers like these can be nested within each other (like Russian dolls). The FESA [7], e.g., uses nested top hat geometry electrostatic analysers to allow two E/Q (energy per charge) ratios of electron to be sampled simultaneously. AMPS [8], on the other hand, is a nested spherical geometry analyser that allows one energy of electron and one E/Q of ion to be sampled simultaneously.

The coaxially nested cylindrical geometry discussed in this paper builds on both of these developments, using 10 levels of nesting to allow five different energies of negative E/Q (hereafter called electron energies) and five different positive E/Q (hereafter called ion energies) to be sampled simultaneously. It uses a cylindrical geometry for ease of manufacture at small scales.

The CATS electrostatic analyser design [9] was developed as a prototype study of this geometry. It is well suited to micro-fabrication methods and was developed primarily for aerospace applications including space weather detectors for nanosatellites and high time resolution instruments for multipoint space physics studies [10,11].

In this paper we explore some of the detail of the nested cylindrical geometry used in the CATS design. Specifically we use high-resolution, Monte-Carlo SIMION charged particle ray-tracing simulations to determine its ideal-world focussing properties and use electron-beam tests to show the impact to the analyser response of real-world manufacturing deviations in the as-built model.

2. CATS geometry

Fig. 1 shows the CATS design; 10 concentric 90° cylindrical electrostatic analysers (hereafter termed "channels"), arising from two contiguous electrodes (shown more clearly later in Fig. 3). The orange coloured sections are an electrically grounded electrode, the black coloured sections are an adjustable voltage electrode.

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If a positive voltage is applied to the black electrode, then the channels suffixed "D" will analyse electrons and the channels suffixed "C" will analyse ions, and vice versa if the voltage is negative.

For any given voltage applied, the peak energy of particles transmitted by an individual ideal cylindrical analyser is determined by the k-factor, K (sometimes called the plate factor) and is approximated by the following equation [13]:

$$K = \frac{E_{selected}}{V_{applied}} = \frac{1}{2\ln\frac{R_{outer}}{R_{inner}}} \approx \frac{R_0}{2 \times \Delta R} \quad (1)$$

where $E_{selected}$ is the peak energy of the successfully transmitted particles (of unit charge), R_{outer} is the radius of the outer (larger) channel wall, R_{inner} is the radius of the inner channel wall, $V_{applied}$ is the potential difference between R_{inner} and R_{outer}, R_0 is the mean radius of curvature of the channel and ΔR is the channel width ($R_{outer} - R_{inner}$). The CATS ΔR and R_0 are shown in Fig. 2.

It can thus be seen that the peak energy analysed increases as the channel number (thus R_0) increases.

Eq. (1) is only an approximation however since it is valid only where the field is directly perpendicular to the curved electrode plates and so does not account for the ends of the analyser: i.e. the x–y plane terminating plate electrodes in the plus and minus Z direction in Fig. 2. The full three-dimensional nature of the electrodes is shown in an exaggerated cutaway schematic view in Fig. 3, displaying the terminating end-plates that connect the black electrodes (construction details are shown in a previous publication [9]).

It can be seen in this figure that both terminating plates (top and bottom sides in this orientation) are marked black, i.e. they are all contiguous with the black coloured electrode and thus are at the potential being applied to the device and not at ground. This means that with a negative applied voltage the ions would be attracted to the these terminating plates and the electrons repelled and vice versa for a positive applied potential. Said another way, the odd numbered ("C", converging) channels will always have an edge-field that concentrates particles towards the centre of the channel, and the even numbered ("D", diverging) channels will always have an edge field that attracts particles towards the terminating plates.

To model the charged particle optics of such arrangements, computer simulations were developed. In the following section these simulations will be used to show how the D and C-channel designs affect the instrument parameters and focussing properties of the CATS analyser.

3. Simulations

The SIMION 8 software package [13] was used to perform charged particle ray tracing simulations. These modelled the CATS geometry as a 3D construction of 6.25 μm length cubes and calculated the electric fields accordingly. Randomised particles

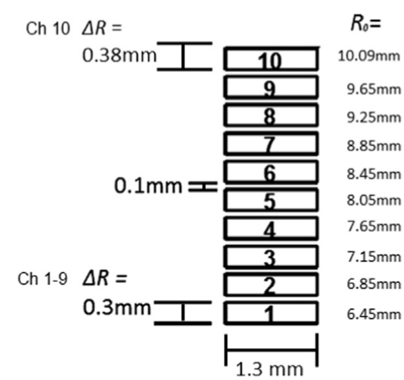

Fig. 2. CATS apertures showing aperture dimensions and key analyser dimensions (entrance and exit apertures are identical). As can be seen in Fig. 1, channel 10 has a larger ΔR due to an oversized R_{outer}, however, its aperture size is the same as the other channels.

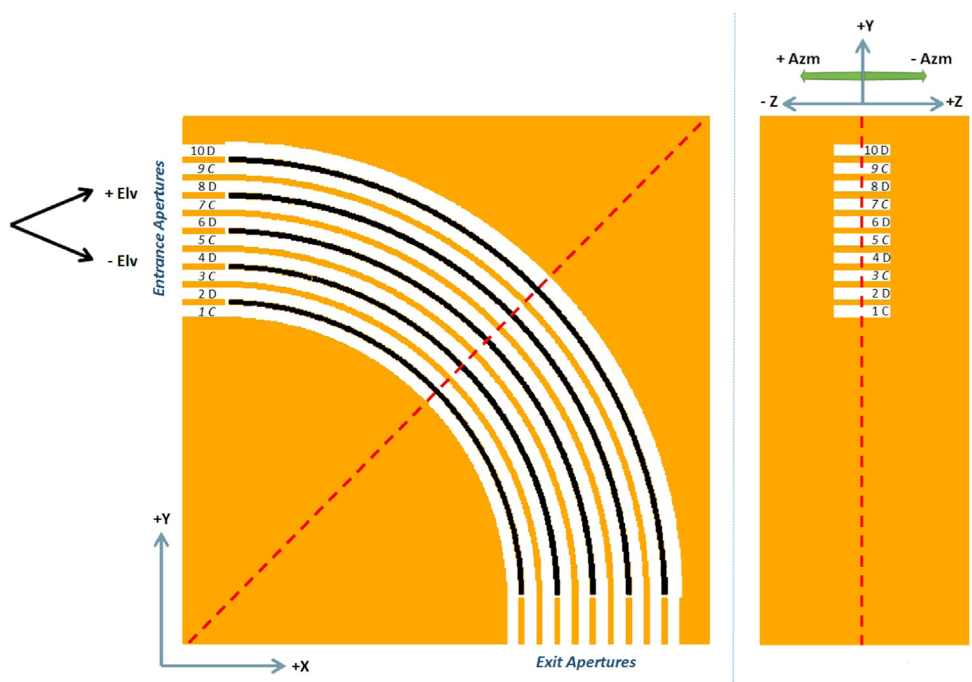

Fig. 1. Left: Central cross-section schematic view of the CATS analyser design. Right: Front view of CATS analyser design showing input (entrance) apertures. Orange indicates grounded electrode, black indicates electrode at analyser voltage, ($V_{applied}$). Dashed lines show lines of symmetry used to optimise simulations. Channel number labels and channel type (C or D – as explained in the text) are also indicated. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this paper.)