Oct. 14, 1969 W. M. BRUBAKER 3,473,019

MASS ANALYZER WITH EXTENSION MEANS TO DECREASE THE DISTANCE BETWEEN ELECTRODE SURFACES

Filed June 19, 1967

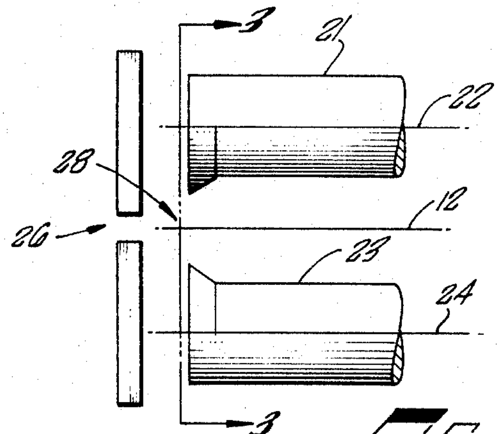


FIG. 2

FIG. 3

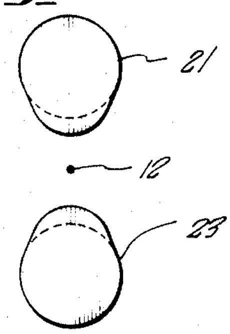


FIG. 4

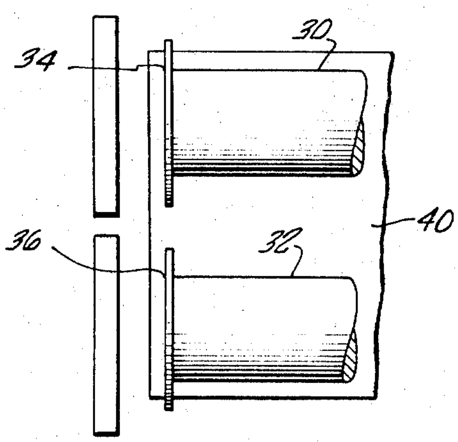
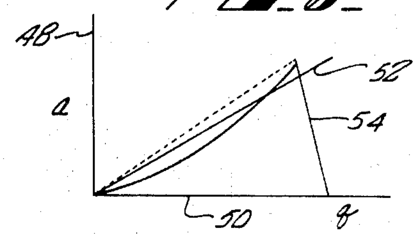


FIG. 6



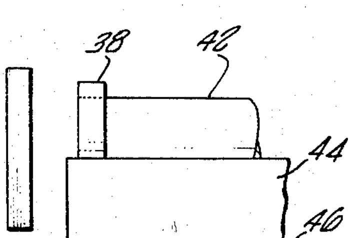


FIG. 5

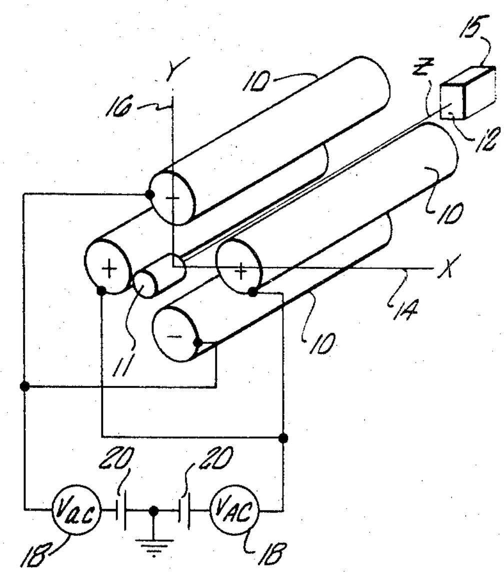


FIG. 1

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3,473,019

MASS ANALYZER WITH EXTENSION MEANS TO DECREASE THE DISTANCE BETWEEN ELECTRODE SURFACES

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Int. Cl. H01j *39/34*
U.S. Cl. 250—41.9 10 Claims

ABSTRACT OF THE DISCLOSURE

A non-magnetic mass analyzer with improved transmission efficiency. In this analyzer the distance between a field electrode or electrodes of the analyzer in the vicinity of the entrance aperture is made smaller than the distance between the electrodes in that portion of the analyzer more remote from the aperture.

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Areonautics and Space Act of 1958, Public Law 85–568 (72 Stat. 435; 42 U.S.C. 2457).

BACKGROUND OF THE INVENTION

This invention relates to a non-magnetic mas analyzer and in particular to a mass filter having specially constructed field-forming electrodes to improve transmission efficiency.

In the operation of non-magnetic analyzers such as monopole and quadrupole mass filters (described in U.S. Patents 3,197,633 and 2,939,952 respectively), it has been found that exposure of charged particles to be analyzed to the fringing electric fields existing at the entrance end of the analyzer for more than two or three cycles of the AC voltage connected to the field-forming electrodes results in an undesirable radial impulse being imparted to the particles. If the impulse is sufficiently high, the charged particles contact and are discharged at the electrodes of the analyzer reducing the quantity of charged particles which would otherwise be transmitted by the analyzer and creating several other undesirable side effects.

In order to reduce the impulse producing effect of the fringing field, a first approach has been to impart a relatively high injection energy to particles as they are directed toward the entrance end of the filter so as to reduce the transit time of the particles through the fringing fields to a minimum. A high injection energy, however, limits the maximum power which can be obtained and imposes additional electric power requirements on the instrument. To restore some of the lost resolving power an analyzer of increased length is often provided in order to permit the analyzing or resolving action of the electric fields within the analyzer to be exerted over a longer distance and particle transit time. Increased analyzer length is frequently undesirable especially when the analyzer is made part of the instrumentation in a space vehicle.

A second approach has been to provide auxiliary electrodes adjacent the entrance end of the instrument. The ratio of the voltages connected to these electrodes is then arranged such that particles entering the analyzer encounter an intermediate ratio in the transition from the region of zero field outside the analyzer to the region of very strong electric fields in the center of the analyzer. This is done by reducing the amplitude of the DC voltage connected to the auxiliary electrodes while leaving the amplitude of the AC voltage unchanged. By this means a substantial increase in the transmission efficiency of

the analyzer is achieved. Such an approach is described in U.S. Patent 3,129,327.

SUMMARY OF THE INVENTION

The present invention provides another approach to the reducing of the effect of the fringing field at the entrance to a non-magnetic mass analyzer. The invention provides a non-magnetic mass analyzer comprising at least one elongated field-forming electrode having a longitudinal axis and a second elongated electrode extending longitudinally of and parallel to the field-forming electrode such that the two or more electrodes define an analyzing region there-between, the analyzing region having a longitudinal axis, an entrance end and an exit end. A source of AC voltage and a source of DC voltage are connected to the field-forming electrode to create a mass analyzing electric field between the two electrodes. A source of charged particles is located at the entrance end of the analyzing region and means for detecting charged particles is located at the exit end of the analyzing region. Extension means are located at the entrance end of the analyzer in an electrically conductive relationship with the field-forming electrode for decreasing the distance between the electrode surface along a line perpendicular to the longitudinal axis of the analyzing region.

By narrowing the distance between the electrodes of a mass analyzer at the entrance end of the instrument, the analyzing electric field now reaches full strength at a position closer to the entrance end of the analyzer. Charged particles entering the analyzer therefore traverse a shorter distance measured along the axis of the analyzer through an electric field of reduced strength, i.e., of the so-called fringing electric field. This reduction in exposure to the fringing field results in a diminution of the radial impulse which would normally be imparted to particles as they pass through such a field.

Reduction of the effect of fringing fields at the entrance of the analyzer in the manner of the present invention permits several advantageous changes in the structure and operating parameters of the analyzer. The length of the analyzer can be reduced and the injection energy can be lowered without a reduction in resolving power or sensitivity. Alternatively, an analyzer having the same overall length as before can be operated at a lower frequency and lower power without any significant degradation of performance.

DESCRIPTION OF THE DRAWINGS

The above advantages and others will be better understood by reference to the following figures in which:

FIG. 1 is a schematic diagram in perspective of a conventional quadrupole mass analyzer;

FIG. 2 is a view of a pair of electrodes of a quadrupole mass analyzer incorporating the improvement of the present invention;

FIG. 3 is a view taken along lines **3—3** of FIG. 2;

FIG. 4 is an alternate embodiment of the invention as incorporated in a quadrupole mass analyzer.

FIG. 5 is a second alternate embodiment of the invention as incorporated in a monopole mass analyzer; and

FIG. 6 is a stability diagram for a quadrupole mass analyzer.

In FIG. 1 is depicted a schematic illustration of a conventional quadrupole mass analyzer. The analyzer includes four elongated field-forming electrodes **10** in the form of cylindrical rods disposed at 90° intervals about a longitudinal axis **12**, designtaed the Z axis. Completing the Cartesian coordinate frame of reference, an X axis **14** and a Y axis **16** lie in the plane of the entrance end of the rod electrodes. The rods lying in the X-plane are referred to as the X or positive rods and the rods lying in the Y-plane are resignated the Y or negative rods. A source of AC voltage 18 and a source of DC voltage 20 are connected to the X- and Y-rods, respectively, such that the positive pole of the DC source is connected to the X-rods and the negative pole of the DC source to the Y-rods. Connection of sources 18 and 20 to the electrodes causes a multipole electric field analyzing region with a longitudinal axis 12 to be created within the analyzer.

In operation the rods are enclosed in a housing (not shown) which is normally evacuated and charged particles, normally ions, from a source 11 are directed into the analyzer longitudinally of the rods and generally along the Z axis toward a detector 15 located at the exit end of the electrodes. The charged particles injected into the analyzing field are then sorted with only particles of a mass to charge ratio determined by the amplitude of the AC and DC voltages and the frequency of the AC voltage being transmitted through the analyzer.

The operation of a quadrupole mass analyzer or filter is frequently described in terms of a diagram such as is shown in FIG. 6, a stability diagram. The parameters indicated along the ordinate 48 and abscissa 50 are proportional, respectively, to the amplitude of the DC and AC voltages connected to the electrodes of the filter. For given specific values of AC and DC voltage, and frequency of AC voltage, the transmission of ions through the analyzer can be termined by reference to line 52 on the diagram, a line designated the scan line. The area under triangular shaped figure 54 is referred to as the stable portion of the diagram. The areas to the left and right outside the triangle are referred to as the Y- and X-unstable portions respectively. Therefore, for the conditions shown in FIG. 6, ions in a narrow mass range corresponding to the points on line 52 just below the apex of the triangle are the only masses transmitted by the analyzer.

The scan line 52 can also be referred to in connection with the conditions experienced by an ion which would normally be transmitted through the analyzer as it passes through the entrance fringing fields. Since the field strengths vary from zero to full value, as the ion traverses this region, ions having a transmissible M/e ratio can be said to have unstable trajectories until they arrive in the region of full field strength, i.e., they correspond to ions having working points which lie on that portion of the scan line in the Y-unstable portion of the stability diagram. In the Y unstable region such ions receive an impulse in the Y-direction away from the axis 12 of the analyzer. A sufficiently strong impulse causes the ion to strike one of the rods and be discharged.

The effect of the fringing field is reduced by shaping the entrance of one or more of the field electrodes as shown in FIGS. 2 and 3. As shown therein the distance between the rods at the entrance end is decreased along a line perpendicular to the longitudinal axis 12 of the analyzing region. Charged particles passing through entrance aperture 26 now move from an era of zero field strength adjacent entrance end 28 of electrodes 21 and 23 to an area of maximum field strength within the interior of the analyzer over a shorter distance and in a shorter time. This reduction in the length of the fringing field along the longitudinal axis of the analyzer means that the charged particles entering the analyzer are exposed to fewer cycles of the AC voltage connected to the electrodes of the analyzer (i.e., they move to the stable portion of the stability diagram in a shorter time span), thereby minimizing the radial impulse which is normally imparted.

Alternate embodiments to the invention depicted in FIGS. 2 and 3 are shown in FIGS. 4 and 5. In FIG. 4 a pair of rod electrodes 30 and 32 are provided with discs 34 and 36 attached to the entrance end of the electrodes in a conductive relationship therewith. A flat electrode 40 completes the structure of a dualpole mass analyzer. As indicated above, the reduction in the length of the fringing field is achieved by reducing the distance between the electrodes of the mass analyzer at the entrance end of the analyzer. Thus the provision of discs at the end of the

rods of an analyzer achieves this objective. Collar 38 disposed around rod electrode 42 achieves the same result as shown in FIG. 5 with right angle electrode 44 completing the structure of a monopole mass analyzer. As the depth of the collar increases, the distance from collar 38 to an axis 46 extending longitudinally of the electrodes 42 decreases.

Although described primarily with reference to a quadrupole mass filter, the improvement of the present invention is also useful in mass analyzers of the monopole and dualpole type. By decreasing the distance between the field-forming electrode or electrodes at the entrance end of the analyzer, the length of the fringing field is reduced and the transmission efficiency increased. The invention can also be described in terms of the diameter of the rod electrodes of a mass analyzer. If the diameter of the electrodes of a mass analyzer in the immediate vicinity of the entrance aperture is made larger than the diameter of the rest of the electrode, then the magnitude of the electric field near the axis of the instrument reach their full value at a position nearer the entrance aperture. The exact shape and extent of the enlargement is not critical. In the preferred embodiment modification of the entrance end of the rods should be symmetrical and the same for each rod. In a quadrupole the modification is preferably made to the Y or negative rods only since the radial impulse normally imparted is Y directed.

The same modification to the field-forming electrode can also be provided with beneficial results at the exit end of the analyzer. A similar impulse producing fringing field also exists at this end of an analyzer and reduction of its effect likewise improves the transmission efficiency of the analyzer.

If the linear dimension of the fringing field along the axis is shortened, several advantages can be obtained. An analyzer which is shorter in length acting on charged particles introduced with a lower injection energy can achieve the same resolving power and sensitivity of an analyzer having rods of uniform contour into which ions of higher injection energy are directed. Alternatively, it is possible to operate an instrument of the same overall length which has been provided with the improvement of this invention at a lower frequency and power without diminishing the resolving power or sensitivity. Put in another way, an instrument made according to the improvement of the present invention outperforms a conventional instrument with all other parameters unchanged. It yields higher sensitivity at a given resolving power or higher resolving power at the same sensitivity.

What is claimed is:

1. A non-magnetic mass analyser comprising:
at least one elongated field-forming electrode;
a second elongated electrode extending longitudinally of and parallel to the field electrode;
a source of AC voltage;
a source of DC voltage;
means for connecting the sources of AC and DC voltage to the field electrode for creating a mass analyzing field region between the two electrodes, the analyzing region having a longitudinal axis located between and substantially parallel to the two electrodes and an entrance end and exit end located at opposite ends of the longitudinal axis respectively;
a source of charged particles located at the entrance end of the analyzing region;
means for detecting charged particles located at the exit end of the analyzing region; and
extension means located at the entrance end of the analyzing region in electrically conductive relationship with the field-forming electrode for decreasing the distance between the electrode surfaces along a line perpendicular to the longitudinal axis of the analyzing region.

2. A mass analyzer according to claim 1 wherein the mass analyzer is of the monopole type with the elongated field-forming electrode having a rod configuration

and the second electrode having a right angle configuration bracketing the field-forming electrode, the extension means being connected to the rod electrode.

3. A mass analyzer according to claim **1** wherein the mass analyzer is of the dualpole type with two field-forming electrodes, each having a rod configuration and the second electrode having a flat configuration, the extension means being connected to at least one of the rod electrodes.

4. A mass analyzer according to claim **1** wherein second extension means are located at the exit end of the analyzing region in electrically conductive relationship with the field-forming electrode.

5. A mass analyzer according to claim **1** wherein the analyzer is of the quadrupole type comprising four field-forming rod electrodes symmetrically disposed about a central axis, the second electrode corresponding to the fourth field-forming electrode, a first pair of opposed rods defining, according to the Cartesian coordinates frame of reference, X rods lying along an X axis of the analyzer and the second pair of opposed rods defining Y rods lying

along a Y axis of the analyzer, the extension means being connected to at least one of the rod electrodes.

6. A mass analyzer according to claim **5** wherein the extension means are connected to the Y rods only.

7. A mass analyzer according to claim **5** wherein the extension means are connected to all four rods of the analyzer.

8. A mass analyzer according to claim **1** wherein the extension means is a conductive disc.

9. A mass analyzer according to claim **1** wherein the extension means is a conductive collar.

10. A mass analyzer according to claim **1** wherein a field-forming electrode is provided in the form of a cylindrical rod and the extension means is a contoured portion of the rod extending toward the second electrode.

References Cited

UNITED STATES PATENTS

3,129,327 4/1964 Brubaker ---------- 250—41.9

WILLIAM F. LINDQUIST, Primary Examiner

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,473,019 Dated October 14, 1969

Inventor(s) Wilson M. Brubaker

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 1, line 29, "mas" should read --mass--;
line 52, after "maximum" insert --resolving--.

Col. 2, line 24, "surface" should read --surfaces--;
line 58, "quadrupole" should read --dualpole--;
line 68, "designtaed" should read --designated--;
line 73, "resignated" should read --designated--

Col. 3, line 26, "termined" should read --determined--;
line 50, after "entrance" insert --end--.

Col. 4, line 6, "electrodes" should read --electrode--.

SIGNED AND
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(SEAL)
Attest:

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