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MASS SPECTROMETER CONTROL SYSTEM UTILIZING AUXILIARY MASS
SPECTROMETER AS A REFERENCE STANDARD

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FIG. 1

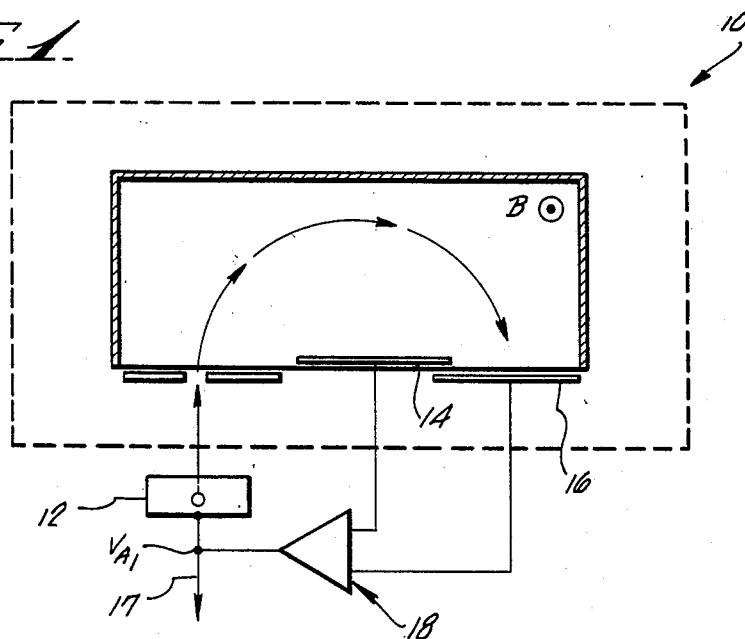
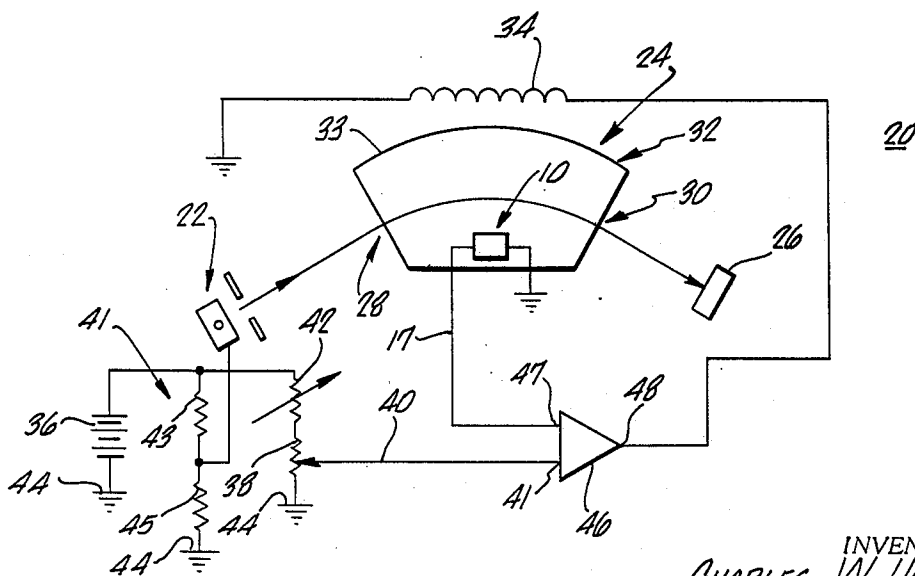


FIG. 2



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ABSTRACT OF THE DISCLOSURE

A mass spectrometer control system for controlling the magnetic field of the controlled mass spectrometer to select the mass in register at the collector. A reference ion transducer operating on the principle of separation of masses according to their mass to charge ratio in a magnetic field is provided utilizing the magnetic analyzing field of the mass spectrometer to be controlled. The reference ion transducer is equipped with a source of reference ions and a pair of long collectors located at the entrance and exit ends of the analyzing field. Any imbalance in the signal detected at the pair of collectors produces a reference control signal which is transmitted through suitable control circuitry to the winding of the electromagnet used to generate the magnetic field in the controlled mass spectrometer. An adjustable voltage divider connected in series with a source of accelerating voltage and the ion source of the controlled mass spectrometer is also connected to the electromagnet control circuitry. Adjustment of the setting of the divider provides a mechanism for obtaining mass scanning.

BACKGROUND OF THE INVENTION

This invention relates to magnetic mass spectrometers and in particular to control systems for such instruments wherein control of the mass in register at the collector is obtained by controlling the magnetic analyzing field.

In conventional magnetic mass spectrometers, one method of obtaining mass scanning is by varying the accelerating voltage in the ion source of the instrument and directing the accelerated particles into the magnetic analyzing field of the instrument. Particles passing through the field undergo a deflection in proportion to their mass which is directly related to the strength of the magnetic field and, depending upon the particular value of accelerating voltage, particles of a predetermined mass are brought into register at the collector located at the exit end of the magnetic analyzing field. Typically in the operation of such instruments, highly regulated power supplies are utilized in order to reduce or eliminate instrument drift tending to obscure and interfere with accurate analysis of the sample introduced into the ion source. Mass scanning in instruments of this type can also be obtained by varying the strength of the magnetic field in the analyzer portion of the instrument. In order to determine the mass value in registered at the collector, some means of measuring and relating the magnetic field to it must be obtained. This approach involves some difficulty due to hysteresis effects in the metal of the electromagnet and the difficulties in determining the "effective magnetic field" over an extended ion path and in taking the effect of the fringing fields at the entrance and exit ends thereof into account. The method most often used is to employ a rotating coil or Hall device to measure the flux and to relate these indications to those obtained in the analysis of a known spectrum.

In still another approach relating to double focussing analyzers, typified by a paper published in Mass Spectroscopy in Physics Research, National Bureau of Standards Circular 522, 1953, p. 29, titled "A Double Focusing Mass Spectrometer" by Dr. A. O. C. Nier, control of a double focussing mass analyzer was obtained by controlling the energy supplied to the electrostatic portion of the mass analyzer. By varying the potential supplied to the plates of the electrostatic analyzer the instrument was made to scan across the mass spectrum of interest bringing masses of various values in the sample into register at the collector.

SUMMARY OF THE INVENTION

The present invention provides a magnetic mass spectrometer comprising a main mass spectrometer having an electromagnetic analyzing sector, a source of ions to be analyzed and a source of accelerating voltage connected to the ion source. A reference analyzing apparatus utilizing the magnetic analyzing sector of the main mass spectrometer is provided for generating a reference signal related to the strength of the magnetic field of the main mass spectrometer. The reference signal is transmitted to circuit means connected to the reference analyzing apparatus for comparing the reference signal and a predetermined proportion of the accelerating voltage of the main mass spectrometer. Means connected to the output of the circuit means responsive to said comparison are also provided for varying the current supplied to the electromagnet to bring a selected mass into registration at the collector.

The reference analyzing apparatus which is also referred to herein as a reference ion transducer is in essence an auxiliary mass spectrometer utilizing the magnetic analyzing field of the controlled mass spectrometer. The reference ion transducer is provided with a source of ions of a predetermined mass which are accelerated by the source, injected into the magnetic field and brought into registration at a pair of "long" collectors located at the exit from the magnetic field of this auxiliary mass spectrometer. The provision of long collectors in the reference ion transducer is advantageous in that the ion peak is always in registration on one of the two collectors of the transducer. This eliminates the possibility that in rapid scanning across the mass spectrum the ion beam in the transducer will fail to register with either of the two collectors thereby resulting in loss of control of the main mass spectrometer.

The present invention is also advantageous in that it provides a reliable method of varying the magnetic field of a mass spectrometer in order to accomplish mass scanning in a manner in which the mass value in registration is proportional to the setting of a voltage divider. Scanning by variation of the magnetic field enables maximizing the mass range of the analyzer and also maximizes the sensitivity of the instrument, both desirable objectives whenever the cost associated therewith is not a serious problem. The present invention provides an economical circuit for accomplishing these objectives.

In addition to the foregoing the present invention also provides a way in which drift in a mass spectrometer can be controlled. As the ion beam in the reference ion transducer tends to go out of balance with reference to its two collectors, a signal is transmitted to control circuitry connected to the collectors corresponding to the direction of the imbalance. Responsive to this signal the control circuitry, in turn, generates an output which determines the amount of energy supplied to the coil of the electromagnet of the magnetic analyzing sector. A corresponding increase or decrease in the energy supplied to the magnet coil increases or decreases the magnetic field in the controlled mass spectrometer restoring the balance of

the ion beam on the long collectors of the reference ion transducer and eliminating any erroneous indications at the collector due to drift.

BRIEF DESCRIPTION OF THE DRAWING

These and other advantages of the present invention will be better understood by reference to:

FIG. 1 which is a schematic illustration of the reference ion transducer of the present invention; and

FIG. 2 is a schematic diagram of a control mass spectrometer utilizing the reference ion transducer of FIG. 1 for generating a magnetic analyzing field control signal.

DESCRIPTION OF A SPECIFIC EMBODIMENT

A reference ion transducer 10 is illustrated in FIG. 1 and comprises a source 12 of charged particles of a predetermined mass and a pair of charged particle collectors 14, 16, disposed in a conventional 180° location relative to the source. Both of the collectors 14, 16 are disposed transversely of the path of the particle beam in a manner conventional in the mass spectrometry art. In addition, in a preferred embodiment each of the collectors is constructed such that its length in this transverse direction is substantially longer than the collectors of comparable conventional mass spectrometers. The length dimension is chosen such that the particle beam is always in registration with one of the two collectors for any selectable value of the magnetic field. In this manner the "long" collectors eliminate the possibility that in rapid scanning the particle beam will overshoot or undershoot the collectors (i.e. the beam will be out of contact with either of the collectors) with resulting loss of control of the operation of the analyzer.

In operation a magnetic field is created in the area between the source and the collectors. The magnetic field and its direction is symbolized by the letter B and the arrow pointing out of the plane of the drawing. The output of the pair of collectors is connected to a differential electrometer amplifier 18 which supplies the accelerating voltage to source 12 for accelerating and directing charged particles from the source into the magnetic field. When the particle beam from source 12 becomes unbalanced with respect to the two collectors and primarily strikes collector 14 the output voltage of electrometer 18 increases, correspondingly increasing the charged particle accelerating voltage. If the particle beam primarily strikes collector 16, the output voltage of the electrometer amplifier is decreased and correspondingly the accelerating voltage is decreased. In this manner the electrical comparison continues until the beam balances half and half (i.e. is equal) on the two collectors. Under such a direction the following relationship holds:

$$V_{A1} = 1/m_1 k b^2 r_1^2$$

where m_1 is the atomic mass of charged particles of a predetermined mass emanating from source 12, k is a constant, B is the magnetic field strength, r_1 is the mean particle radius of particles of mass m_1 and V_{A1} is the accelerating voltage to which particles of mass m_1 are subjected.

The accelerating voltage (V_{A1}) is also applied as a reference via electrical connection 17 to the electromagnet utilized to create the magnetic field between the source 12 and the collectors 14, 16 and when compared against a predetermined proportion of the ion accelerating voltage (V_{A2}) by means of suitable circuit means in a controlled or main mass analyzer utilizing the same magnetic field for analysis, renders the mass in register at the collector of the main analyzer proportional to the predetermined proportion of the accelerating voltage (V_{A2}). Put another way, selection of a specific proportion of the accelerating voltage produces a change in the current supplied to the electromagnet thereby bringing charged particles of a

selected mass into registration at the collector of the controlled mass analyzer.

Such an arrangement is illustrated in FIG. 2. In that figure a controlled magnetic mass spectrometer 20 is shown having a source 22 of charged particles such as ions to be analyzed, a magnetic analyzing sector 24 and a particle collector 26. The source 22 and collector 26 are located respectively at an entrance end 28 and exit end 30 with respect to the analyzing field created in sector 24. The magnetic analyzing field is created by means of an electromagnet 32 having a pair of pole pieces 33 and coil 34. Shown schematically in FIG. 2 is one of the pole pieces 33 in magnetic field creating relationship with the electromagnet energizing coil 34.

Source 22 is electrically connected to a voltage divider 41 comprising a pair of series connected resistors 43, 45 at a point between the two resistors. The side of resistor 43 opposite the connection point to source 22 is connected to a source of accelerating voltage 36 and to a voltage divider 38 having an adjustable tap 40. The accelerating voltage (V_{A2}) accelerates and directs charged particles out of the source toward the analyzer portion of the instrument with which it is associated. An adjustable resistor 42 is also provided in series circuit relation with divider 38, the side of resistor 42 opposite the connection to divider 38 being connected to the connection point common to source 36 and resistor 43, for providing fine adjustments of the proportion of the voltage supplied to tap 40. The sides of source 36 and divider 38 opposite the connection to resistor 43 as well as the side of resistor 45 opposite the connection point to source 22 are connected to a source of reference voltage 44 such as ground potential. The voltage divider 38 and adjustable tap 40 provide the means whereby scanning of the various masses present in the sample supplied to the ion source of the controlled mass spectrometer is accomplished. Scanning of the masses is obtained by adjusting the position of the tap along the divider.

Resistors 43 and 45 of voltage divider 41 divide the voltage from source 36 to permit the accelerating voltage (V_{A2}) to be a fraction of the total voltage available at tap 40. This permits the instrument to be used where the ion in the reference ion beam is a light mass, e.g., an ion such as $^4\text{He}^+$. In such an analysis a high accelerating voltage (V_{A1}) is required. The use of a high voltage (V_{A1}) is of further advantage in that it allows the main analyzer to be operated over a large mass range. Where the voltage at tap 40 is to be a fraction (less than unity) of the main accelerating voltage (V_{A2}) resistor 43 is chosen small compared to resistor 45.

Tap 40 from voltage divider 38 is connected to a first input terminal 41 of an electromagnet regulator 46 (in a preferred embodiment, a differential electrometer amplifier) for supplying a predetermined proportion of the charged particle accelerating voltage (V_{A2}) of spectrometer 20 to the regulator. Connected to a second input terminal 47 of regulator 46 is an electrical lead 17 from the output of electrometer 18 of the reference ion transducer 10 to supply a reference or control signal (V_{A1}) related to the strength of the magnetic field in the analyzer. The two input signals cause the output of regulator 46 to drive until a balance of the inputs is achieved. The output or drive signal from output terminal 48 of regulator 46 is connected to the energizing coil 34 of the electromagnet. Depending on the increasing or decreasing nature of the signals received at terminals 41, 47 of the regulator, the output of the regulator is increased or decreased accordingly to change the magnetic analyzing field of the two analyzers in a manner tending to restore a balance of the ion beam on the two collectors 14, 16 of the reference ion transducer 10. The use of V_{A1} as a reference for the electromagnet and as a means of controlling the main mass spectrometer is accomplished in the

following manner: The electromagnet regulator 46 is arranged to drive until its inputs are equal. In this manner

$$f \times V_{A2} = V_{A1} \text{ (the balance relationship)}$$

where f is the setting of voltage divider 38 corresponding to the predetermined portion or proportion of the potential (V_{A2}) which is supplied to the end of the inputs of electromagnet regulator 46. V_{A2} is also the accelerating voltage to which charged particles in source 22 of the main mass spectrometer are subjected. The mass m_2 in register at the collector, is given by

$$m_2 = 1/V_{A2} k B^2 r_2^2$$

where m_2 is the mass in register at the collector, r_2 is the mean particle radius of particles of mass m_2 and the other parameters are as outlined above. Combining this relationship with the balance relationship, the result is

$$f = m_2 / m_1 r_1^2 / r_2^2 \\ = L m_2$$

where L is a constant.

Thus the number or fraction set on divider 38 is always proportional to the mass m_2 in register at the collector 26. In this manner the accelerating voltage (V_{A2}) can be changed without changing the output mass m_2 and the power supplies for the instruments need not be highly regulated since the regulation comes from auxiliary mass spectrometer or reference ion transducer 10. The divider can further be actuated in a number of ways such that the mass number of the particle in registration at the collector can be correlated with spectral data.

The use of the present control system in mass scanning applications is particularly advantageous. A change in the setting f of the voltage divider 38 causes electromagnet regulator 46 to drive causing the magnetic field in the analyzing sector 24 to change. A change in the magnetic field produces an imbalance in the ion beam impinging on the two collectors of the auxiliary mass spectrometer and the electrometer (18, 46) outputs change correspondingly producing a change in the accelerating voltage V_{A1} to restore ion beam balance at the collectors and similarly producing a change in the second input 47 to the magnet regulator. Adjustment continues in this manner until the ion beam is balanced at the collectors thereby assuring and verifying that the mass selected on the voltage divider is brought into register at the main mass spectrometer collector 26.

The present invention has applicability in the function of maintaining the selected mass m_2 in registration at the collector avoiding problems of drift normally present in the use of conventional mass spectrometers. As the magnetic field in the analyzer 24 tends to drift, the ion transducer 10 again experiences an imbalance of the beams impinging on the collectors, generating a signal causing the magnet regulator 46 to adjust the energization supplied to the electromagnet coil 34 and restoring the ion beam balance in the ion transducer.

In a similar manner a change, accidental or deliberate, in the accelerating voltage (V_{A2}) applied to the particles to be analyzed does not produce a change in the output mass in register at the collector. The correct proportion of the changed voltage is transmitted to the magnet regulator producing an output signal which changes the energization supplied to the electromagnet and the magnetic field within the analyzer. If the accelerating voltage (V_{A2}) has increased thereby tending to bring a lighter mass into register at the collector, the magnet regulator generates a signal increasing the current to the electromagnet and causes the ion beam in the reference transducer 10 to strike collector 14. To compensate, the electrometer 18 senses the difference in the signal from the two collectors 14, 16 and increases its output voltage (V_{A1}) tending to restore the balance. The increased voltage (V_{A1}) is also transmitted to the magnet regulator increasing its output and the current in the electromagnet coil thus increasing

the strength of the magnetic field in the analyzing sector. The increase in the magnetic field due to the increased current compensates for the increase in accelerating voltage (V_{A2}) restoring mass m_2 in registration at the collector. In a similar manner where voltage (V_{A2}) happens to decrease, essentially the same sequence of operation occurs in reverse to restore the originally selected mass in registration at the collector of the controlled mass spectrometer.

What is claimed is:

1. A magnetic mass spectrometer comprising:

a main mass spectrometer having an electromagnet analyzing sector for creating a mass analyzing magnetic field therein, a source of charged particles to be analyzed located on the entrance side of the sector, a source of accelerating voltage connected to the particle source and a charged particle collector located on the exit side of the sector;

a reference standard utilizing the magnetic field of the electromagnet analyzing sector of the main mass spectrometer for generating a reference signal related to the strength of said magnetic field; and

circuit means connected to the reference standard for comparing the reference signal and a predetermined proportion of the accelerating voltage of the main mass spectrometer ion source and for varying the electric current supplied to the electromagnet responsive to said comparison to bring charged particles of a selected mass into registration at the collector.

2. A magnetic mass spectrometer according to claim 1 wherein the reference standard is an auxiliary mass spectrometer having a source of charged particles of a predetermined mass located at the entrance of the magnetic analyzing sector and collector means located at the exit from the magnetic analyzing sector for sensing changes in the charged particle beam as the magnetic field in the sector changes.

3. A mass spectrometer according to claim 2 wherein the collector means is a pair of collectors disposed transversely of the plane of the charged particle beam of the reference standard, each of the collectors having a length dimension in said transverse direction sufficiently long such that the charged particle beam of the reference apparatus always impinges on one of the two collectors for any selectable value of the magnetic field in the analyzing sector.

4. A mass spectrometer according to claim 3 wherein the circuit means is an electrometer amplifier arranged to generate a signal responsive to the reference signal and the predetermined proportion of accelerating voltage altering the current to the electromagnet and the magnetic field in the electromagnetic analyzing sector until the charged particle beam in the auxiliary mass spectrometer balances on the pair of collectors provided therewith.

5. A magnetic mass spectrometer control system comprising:

a main mass spectrometer having an adjustable electromagnetic analyzing sector for creating an analyzing magnetic field therein, a source of charged particles to be analyzed, means for accelerating and directing particles from the source and a collector upon which analyzed particles impinge;

an auxiliary magnetic mass spectrometer having a source for producing and adjustably accelerating a charged particle reference beam therefrom, a curved particle beam path passing through the analyzing sector of the main mass spectrometer, a pair of reference beam collectors disposed adjacent each other at the end of the reference beam path opposite the source, electrical circuit comparison means connected to the collectors for producing a control signal as long as the portions of the reference beam incident on each collector are unbalanced, and circuit means interconnecting the output of the comparison means

and the auxiliary mass spectrometer source for adjusting the acceleration of the reference beam;
 an electromagnet regulator connected to the electromagnet of the analyzing sector of the main mass spectrometer for adjusting the magnetic field responsive to the control signal;
 a voltage divider connected to the charged particle source and the accelerating and directing means of the main mass spectrometer, the voltage divider having an adjustable tap; and
 circuit means for connecting the auxiliary mass spectrometer control signal and the voltage divider tap to the electromagnet regulator whereby the setting of the adjustable tap is proportional to the mass in register at the collector of the main mass spectrometer.

6. A mass spectrometer according to claim 5 wherein each of the pair of collectors is arranged such that its major dimension is located transversely of the beam and the length of each of the collectors along said dimension is chosen such that the charged particle beam cannot be out of contact with at least one of the collectors for any value of the magnetic field in the analyzing sector.

7. A mass spectrometer according to claim 6 wherein the electromagnet regulator and the electrical circuit comparison means are electrometer amplifiers which are arranged to generate an output signal until the signals on the input side thereof are balanced.

8. A magnetic mass spectrometer control system comprising:

a first mass spectrometer having an adjustable electromagnet for creating a magnetic analyzing field, a source of ions to be analyzed located at an entrance to the magnetic field, a source of accelerating voltage connected to the ion source for accelerating and directing ions into the magnetic field, and an ion collector located at an exit from the field;

a reference ion transducer utilizing the magnetic analyzing field of the first mass spectrometer, the ion transducer having a source of reference ions of a predetermined mass, means for accelerating and directing a reference ion beam into said magnetic field, a pair of long ion collectors disposed adjacent each other located at the reference ion exit from the magnetic field, electrical circuit comparison means interconnecting the collectors and the accelerating means for producing a control signal for adjusting the acceleration of the reference ions until the portions of the reference ion beam incident on each collector are balanced;

an electromagnet regulator connected on its output side to the electromagnet of the first mass spectrometer for adjusting the magnetic field;

a voltage divider connected to the accelerating voltage source of the first mass spectrometer, the voltage divider having an adjustable tap for obtaining a proportion of the accelerating voltage connected to the ion source; and

circuit means for connecting the reference ion transducer control signal and the proportion of the accelerating voltage obtained by the voltage divider tap to the electromagnet on its input side whereby a mass scan can be performed by the first mass spectrometer by adjusting the position of the tap on the voltage divider.

9. A control system according to claim 8 wherein each of the pair of collectors is disposed transversely of the plane of the reference and has a length dimension in said transverse direction such that the ion beam cannot be out of contact with one of the collectors for any selectable value of the magnetic analyzing field.

10. A control system according to claim 8 wherein the electromagnet regulator and electrical circuit comparison means are electrometer amplifiers which are arranged to drive until their inputs are equal.

11. A control system according to claim 9 wherein the adjustable electromagnet comprises an electromagnet energizing coil and a pair of pole pieces, the coil being located in magnetic field creating relationship with respect to the pole pieces and being electrically connected to the output of the electromagnet regulator.

12. A control system according to claim 11 wherein the electromagnet regulator is arranged to adjust the current supplied to the coil of the electromagnet until the control signal and the obtained proportion of the accelerating voltage of the first mass spectrometer connected to the regulator are balanced.

13. A mass spectrometer according to claim 12 including means for finely adjusting the proportion of the accelerating voltage connected to the electromagnetic regulator.

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