April 22, 1952 H. W. WASHBURN 2,593,508

VARIABLE SHUNT PERMANENT MAGNET

Filed Oct. 16, 1948

FIG. 1.

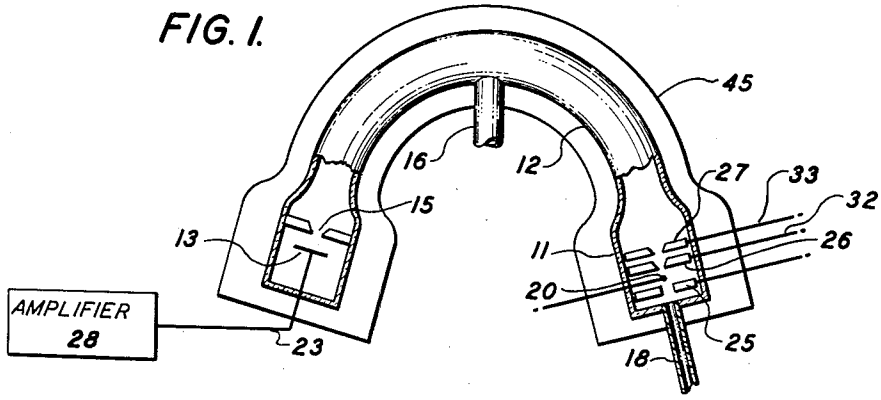


FIG. 2.

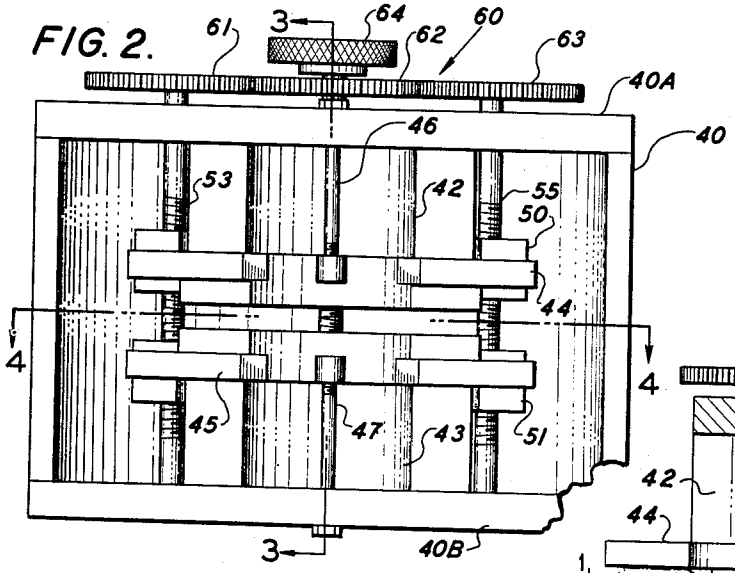


FIG. 3.

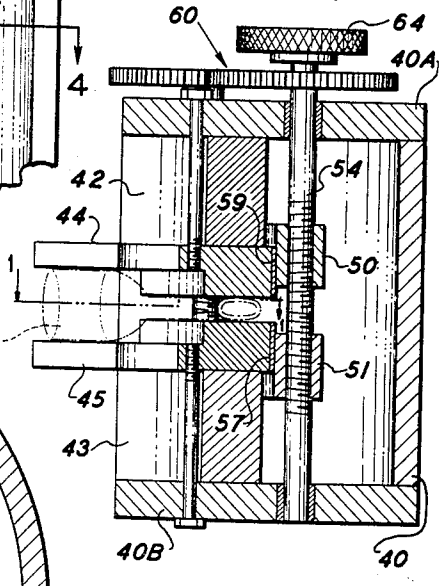
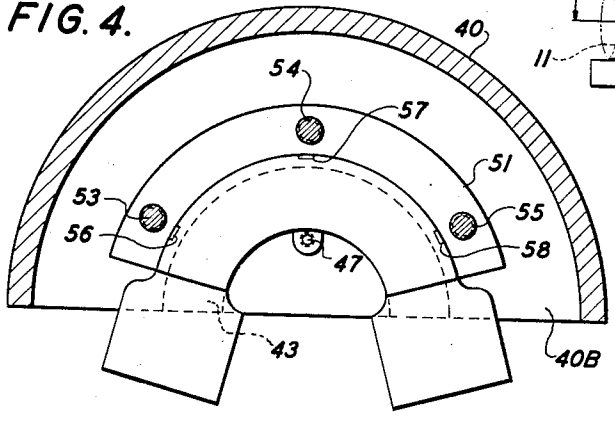


FIG. 4.



INVENTOR.
HAROLD W. WASHBURN

BY

James R. Whistler

ATTORNEY

Patented Apr. 22, 1952

2,593,508

UNITED STATES PATENT OFFICE

2,593,508

VARIABLE SHUNT PERMANENT MAGNET

Harold W. Washburn, Pasadena, Calif., assignor to Consolidated Engineering Corporation, Pasadena, Calif., a corporation of California

Application October 16, 1948, Serial No. 54,957

10 Claims. (Cl. 250—41.9)

1

This invention relates to a variable shunt permanent magnet and more particularly to the use of such variable shunt magnet in mass spectrometry.

A mass spectrometer is an analytical apparatus which functions to sort and measure ions. Ordinarily it includes an ionization chamber into which molecules of the sample to be analyzed are introduced. In the ionization chamber the molecules are bombarded by a stream of electrons and converted into ions. So-called propelling or accelerating electrodes propel the ions from the ionization chamber into and through an analyzer chamber. During passage through the analyzer chamber the ions are subjected to a transverse electric or magnetic field or both to separate them according to their mass-to-charge ratios into a plurality of diverging ion beams. Each ion beam is composed of ions of the same specific mass and differing from the mass of the ions forming other beams. The diverging beams are successively focused on an ion collector by varying the potential applied to the accelerating electrode or by varying the intensity of the transverse field in the analyzer tube. The current produced by the discharge of each beam on the ion collector is a measure of the partial pressure of the molecules (from which the ions were derived) in the sample being analyzed.

As indicated above, the diverging ion beams may be focused on the ion collector by varying the potential applied to the accelerating electrodes or by varying the strength of a transverse magnetic field. The focusing of successive beams on the ion collector is commonly referred to as "scanning." The advantages of using magnetic scanning, i. e. slow variation in the strength of the transverse magnetic field rather than electric scanning, i. e. variation in the potential applied to accelerating electrodes, may be listed as follows:

1. The mass spectra obtained with magnetic scanning are more constant than the mass spectra obtained with electric scanning. This is due to the following facts:

a. When magnetic scanning is used the shift in a position of the electron beam is less than when electric scanning is used.

b. When electric scanning is used any variation with time of space charges or surface charges will cause variations in the spectra. The effect of the space charges or surface charges is less apparent when magnetic scanning is used and consequently the variations resulting therefrom are minimized.

c. The "voltage effect," about which very little

2

is known, has less effect on magnetic scan than on electric scan.

2. A wider range of masses may be covered in a single sweep when magnetic scanning is employed.

Further, there are two methods of scanning by means of the magnetic field. One such method involves gradually varying the current supplied through an electro magnet by means of which the magnetic field is established.

Another means described in the present invention comprises gradually varying the effective strength of the field established by a permanent magnet. I accomplish this by adjustment of the mechanical position of a permeable shunt across the gap of a permanent magnet in which gap the so-called analyzer tube or chamber of the mass spectrometer is disposed. A permanent magnet with a variable shunt as described and illustrated herein has several advantages over an electro-magnet provided with means for varying the current. These advantages include:

1. The permanent magnet can be made in almost any shape desired. In its application to mass spectrometry this permits a reduction of the total area of the magnetic field to a minimum which in turn makes possible a small compact unit.

2. When using a mechanical shunt a power supply and current control circuit are eliminated. In general, mechanical devices are simpler to maintain and service, particularly when the personnel using the instruments are not trained in electronics.

3. The mechanical motion employed to move the shunt can be simply transferred to a calibrated dial which will read the mass directly. The mechanical shunt arrangement therefore makes possible a simple mass marker.

The present invention is directed to a variable shunt permanent magnet having spaced opposite poles defining an air gap in which a magnetic field is established, and a magnetically permeable member associated with the poles and movable adjacent the air gap to shunt a portion of the magnetic flux through the member. In a preferred embodiment two such permeable shunts are provided; one in association with each pole defining the air gap. Mechanical means are provided for moving the two shunts simultaneously so that their displacement is equal and opposite. As the shunts are brought closer together a greater proportion of the magnetic flux is by-passed through the shunts thus weakening the field strength in the air gap.

One obvious application of such a variable

shunt permanent magnet is in the field of mass spectrometry. As above described it is conventional practice to establish a magnetic field across the analyzer of a mass spectrometer. Accordingly, the invention also contemplates in a mass spectrometer comprising an ion source an analyzer tube, means for propelling ions from the ion source through the analyzer tube and means for producing a magnetic field across the analyzer tube transverse to the path of ion travel, the improvement comprising a permanent magnet having its poles arranged on opposite sides of the analyzer tube so that the analyzer tube lies in an air gap between the poles, and means for varying the strength of the magnetic field across the air gap.

The means for varying the strength of the magnetic field across the air gap comprises, in accordance with the foregoing description, a magnetic shunt disposed adjacent one pole of the magnet and adjustable by mechanical means to reduce or increase the distance between the shunt and the opposite pole. As the name implies, the shunt acts as a by-pass through which the magnetic flux tends to travel between the two poles when the reluctance of the path through the shunt is less than the reluctance of the air gap. As the distance between the shunt and the opposite pole decreases the field strength across the air gap is reduced and as the distance between the shunt and the opposite pole increases the field strength across the air gap is increased.

A particular feature of the invention is that the shunt is preferably constructed in two parts, each part being in contact with one of the magnetic poles. The two parts of the shunt are mounted on the same shafts and the motion of the shunts toward or away from the opposing pole pieces is made equal and opposite by the use of the left and right hand threads on the shafts. Thus as the several shafts are turned the two shunts, each contacting a separate pole piece, are forced closer together so as to decrease the reluctance of the shunt circuit and thus reduce the field strength across the air gap. Conversely, as the several shafts are turned in the opposite direction the two shunts are separated so as to correspondingly increase the reluctance of the shunt circuit and the field strength across the air gap. Since the forces, parallel to the shaft or shafts, which are due to the action of the magnetic field on the shunts, are approximately equal and opposite these forces merely cause longitudinal stresses in the shaft and exert practically no resultant force on the end bearing.

The invention will be more clearly understood by reference to the following detailed description thereof taken with relation to the accompanying drawings in which:

Fig. 1 is a plan view taken on the line 1—1 of Fig. 3 showing diagrammatically a part of a mass spectrometer and its relation to one pole of the permanent magnet.

Fig. 2 is an elevation of a variable shunt permanent magnet such as is employed with the ion source and analyzer tube shown in Fig. 1.

Fig. 3 is a sectional elevation taken on the line 3—3 of Fig. 2 with the mass spectrometer analyzer tube and ion source shown in phantom.

Fig. 4 is a plan view taken on the line 4—4 of Fig. 2.

In the drawings, the variable shunt permanent magnet of the invention is shown as constructed for use in a 160° mass spectrometer of the type wherein propelling electrodes are provided in the ion source. As will be apparent from the following description, the invention is not limited in its utility to mass spectrometry. Further, it is equally adapted to use with a mass spectrometer of substantially any curvature and is independent of the particular means employed for ionizing the sample molecules, propelling the sample molecules from the ionization chamber and the like.

In Fig. 1 a part of a mass spectrometer including the analyzer tube, ion source, and ion collector is illustrated diagrammatically as it would appear in plan in relation to one pole of the variable magnet. Fig. 1 is a view taken substantially on the line 1—1 of Fig. 3 wherein a part of the mass spectrometer is shown in phantom.

As shown in Fig. 1 the mass spectrometer comprises an ionization chamber 11, an analyzer tube 12, and an ion collector 13 all of which are kept at low pressures during the operation of the instrument. The analyzer tube 12 is provided, at the end adjacent the ion collector 13, with an exit slit 15 through which ion beams are focused onto the collector 13 by means hereinafter described.

The spectrometer is provided with a pumping system exhaust line 16 which may be connected with a mercury diffusion pump, molecular pump, or any appropriate evacuating system not shown. An inlet line 18 provides means for introducing a sample to be analyzed. An electron gun 20 discharges a beam of electrons through the ionization chamber to ionize molecules as they pass from the inlet tube 18 into the chamber. Propelling electrodes 26, 27 are disposed within the ion source so as to propel the ions formed therein into and through the analyzer tube. Representation of this particular ion source is for illustrative purposes only, there being many modifications thereof equally applicable to the invention.

As above described, the ions propelled from the source are formed in the analyzer tube into diverging beams of ions of a given specific mass. These diverging beams are successively focused on the ion collector 13 through the exit slit 15 by varying the magnetic field established in the analyzer tube 12 by means of the magnet shown in Figs. 2, 3 and 4. One pole 45 of the magnet is shown in Fig. 1. The ion collector 13 is linked with an amplification and sensing circuit (not shown) by a lead 23 sealed through the wall of the envelope 13. The lead 23 connects the collector 13 to an amplifier 28 which is in turn linked to a sensing means (not shown) such as a recorder or the like.

Accelerating electrodes 26, 27 are connected through lead 32, 33 respectively to a conventional voltage supply circuit (not shown). In a similar manner the propelling electrode 25 and the electron gun 20 are connected to a more or less conventional voltage supply circuit.

The variable transverse magnetic field employed to focus successive ion beams through the slit 15 in accordance with the invention is established by means of apparatus shown in Figs. 2, 3 and 4. Referring to these figures the variable shunt permanent magnet comprises a permeable, semi-cylindrical yoke 40 in which are disposed two arcuate permanent magnets 42, 43. The magnets 42, 43 are held against the end walls 40A and 40B respectively of the yoke 40.

The magnets are provided at their inner ends

with aligned arcuate pole pieces **44, 45** respectively which are separated from each other by an air gap. The pole pieces are held against the inner ends of the magnets **42, 43** respectively by means of bolts **46, 47** extending inwardly from the end faces **40A, 40B** of the yoke. The shape of the pole pieces is such that the air gap is bigger adjacent opposite ends. In this manner the relatively enlarged ends of the spectrometer tube necessary for the formation of the ion source and the collector chamber are accommodated between the pole pieces. (See Fig. 3.)

The field strength across the air gap is a function of the dimensions of the gap and of the strength of the permanent magnets **42, 43.** To permit mechanical variation of this field strength I provide a pair of adjustable shunts **50, 51.** The two shunts **50** and **51** engage the opposite pole pieces **44** and **45** respectively and are mounted on a plurality of shafts **53, 54** and **55.** Both shunts are mounted on the same shafts and the motion of the shunts is made equal and opposite by the use of left hand and right hand threads on the shafts.

Referring to Fig. 3 it will be noted that the shaft **54** has right hand threads engaging the shunt **50** and left hand threads engaging the shunt **51.** Rotation of the shaft **54** and likewise the simultaneous rotation of the shafts **53, 55** will cause the shunts **50, 51** either to approach each other or retreat from each other at the same rate. Since the forces, parallel to the shafts, which are due to the action of the magnetic field on the shunts are approximately equal and opposite these forces merely cause longitudinal stresses in the shafts and exert practically no resultant force on the end bearings of the shaft. Likewise side thrusts on the shunts are transmitted to bronze bearing inserts so that these side thrusts are not taken up by the several shafts. Inserts **56, 57, 58** associated with the shunt **51** are shown in Fig. 4 and one such insert **59** associated with the shunt **50** is visible in Fig. 3. This arrangement makes the mechanically moving system smooth in its operation.

Interlocking gear means **60** connected to the several shafts **53, 54, 55** permit simultaneous rotation of the shafts.

The gear means comprises three spur gears **61, 62, 63** affixed to the ends of shafts **53, 54, 55** respectively adjacent the outer face of the yoke end **40A.** The several gears are all of the same size and type so that application of a rotational force to one will be transmitted to the others without speed variation. However, the direction of rotation of the several gears will vary. Depending on which is the drive gear, the threading on the several shafts is arranged so that rotation thereof will cause uniform movement of the two shunts. In Fig. 2, the center gear **61** is represented by means of the knob **64** as the drive gear. Since gears **61** and **63** will rotate in the opposite direction than that of gear **62,** the threading on shafts **53, 55** is opposite to that on shaft **54.**

Any means may be employed to drive the several gears. In automatic mass spectrometer operations it may be desirable to employ motor drive means so synchronized that shunt displacement may be calibrated in terms of the mass of the ions focused on the collector electrode. Further, each of the mounting shafts **53, 54, 55** may be separately and synchronously rotated, although the simple gear arrangement shown is preferred.

The maximum field strength across the gap will be obtained when the shunts are in the open position as shown in Fig. 3. However, as these shunts are forced toward each other by counterclockwise rotation of shaft **54** and clockwise rotation of shafts **53, 55** the magnetic field set up between the opposing poles of the two permanent magnets **42, 43** will be by-passed through the shunts so as to reduce the flux within the air gap.

I claim:

1. A variable shunt magnet for producing a controlled variable magnetic field in a mass spectrometer and comprising a pair of permanent magnets arranged with one pair of opposite poles defining an air gap, a permeable yoke connecting the other pair of opposite poles, a permeable member disposed adjacent the air gap in contact with one of the poles to shunt a portion of the flux away from the air gap and means for moving the permeable member in relation to the air gap to vary the portion of the flux shunted through the member.

2. A variable shunt magnet for producing a controlled variable magnetic field in a mass spectrometer and comprising a pair of permanent magnets arranged with one pair of opposite poles defining an air gap, a permeable yoke connecting the other pair of opposite poles, a separate permeable member in contact with each of the poles defining the air gap and disposed adjacent the air gap, to shunt a portion of the flux away from the air gap and means for adjusting the permeable members in relation to the air gap to vary the portion of the flux shunted away from the air gap.

3. A variable shunt permanent magnet for producing a controlled variable magnetic field in a mass spectrometer and comprising a permeable yoke, a pair of permanent magnets mounted in the yoke with one end of each magnet engaging the yoke, a separate pole piece mounted on the other end of each magnet and defining an air gap between said other ends of the two magnets, a separate permeable shunt engaging each pole piece adjacent the air gap and adapted to shunt a portion of the flux away from the air gap, and means for moving the two shunts with respect to each other to vary the strength of the magnetic field in the gap.

4. Apparatus according to claim 3 wherein both shunts are threaded on a plurality of shafts, one end of each of the shafts being journaled through the yoke, means for rotating all of the shafts simultaneously and at the same rate, each shaft being threaded in opposite directions in the portions thereof passing through the two shunts so that rotation of the shafts causes equal and opposite linear motion of the shunts.

5. Apparatus according to claim 4 wherein the means for rotating all of the shafts simultaneously comprises a separate gear mounted on the outer end of each shaft, the several gears being identical and interlocking and means for applying a driving force to one of the gears.

6. In a mass spectrometer comprising an ion source, an analyzer tube, means for propelling ions from the ion source through the analyzer tube and means for producing a magnetic field in the analyzer tube transverse to the path of ion travel, the combination comprising means for producing a controlled variable magnetic field across said analyzer tube and including a pair of permanent magnets arranged with one pair of opposite poles disposed on opposite sides of the analyzer tube so that the analyzer tube lies

in the air gap between the poles, a permeable member disposed adjacent the air gap in contact with one of the poles to shunt a portion of the flux away from the air gap and means for moving the permeable member in relation to the air gap to vary the portion of the flux shunted through the member.

7. In a mass spectrometer comprising an ion source, an analyzer tube, means for propelling ions from the ion source through the analyzer tube and means for producing a magnetic field in the analyzer tube transverse to the path of ion travel, the combination comprising means for producing a controlled variable magnetic field across said analyzer tube and including a pair of permanent magnets arranged with one pair of opposite poles disposed on opposite sides of the analyzer tube so that the analyzer tube lies in the air gap between the poles, a permeable yoke connecting the other pair of opposite poles, and two permeable members disposed adjacent the air gap each being in contact with one of the poles to shunt a portion of the flux away from the air gap and means for adjusting the permeable members in relation to the air gap to vary the portion of the flux shunted away from the air gap.

8. In a mass spectrometer comprising an ion source, an analyzer tube, means for propelling ions from the ion source through the analyzer tube and means for producing a magnetic field in the analyzer tube transverse to the path of ion travel, the combination comprising means for producing a controlled variable magnetic field across said analyzer tube and including a permeable yoke, a pair of permanent magnets mounted in the yoke with one end of each magnet engaging the yoke, a separate pole piece mounted on the other end of each magnet and arranged on opposite sides of the analyzer tube so that the analyzer tube lies in an air gap between the pole pieces, a separate permeable shunt engaging each pole piece adjacent the air gap and adapted to shunt a portion of the flux away from the air gap, the shunts being movable with respect to each other to vary the strength of the magnetic field in the gap.

9. In a mass spectrometer comprising an ion source, an analyzer tube, means for propelling the ions from the ion source through the analyzer tube and means for producing a magnetic field in the analyzer tube transverse to the path of ion travel, the combination comprising means for producing a controlled variable magnetic field across said analyzer tube and including a permeable yoke, a pair of permanent magnets mounted in the yoke with one end of each magnet engaging the yoke, a separate pole piece mounted on the other end of each magnet and arranged on opposite sides of the analyzer tube so that the analyzer tube lies in an air gap between the pole pieces, a separate permeable shunt engaging each pole piece adjacent the air gap and adapted to shunt a portion of the flux away from the air gap, the two shunts being threaded on a plurality of rods journaled to the yoke, each rod extending through both shunts and one end of each rod extending beyond the yoke, means for rotating all of the rods simultaneously and at the same rate, and each rod being threaded in opposite directions in the portions thereof passing through the two shunts so that rotation of the rods causes equal and opposite linear motion of the shunts.

10. A variable shunt permanent magnet for producing a controlled variable magnetic field in a mass spectrometer and comprising a permeable yoke, a pair of permanent magnets mounted in the yoke with one end of each magnet engaging the yoke, a separate pole piece mounted on the other end of each magnet and defining an air gap between said other ends of the two magnets, a separate permeable shunt mounted in proximity to the pole pieces adjacent to the air gap and adapted to shunt a portion of the flux away from the air gap, a separate bronze bushing mounted between each pole piece and the respective shunt with the pole piece and the shunt engaging the bushing, and means for moving the two shunts with respect to each other to vary the strength of the magnetic field in the gap.

HAROLD W. WASHBURN.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
265,485	Cochran	Oct. 3, 1882
2,309,414	Nobbs	Jan. 26, 1943
2,412,237	Washburn et al.	Dec. 10, 1946

FOREIGN PATENTS

Number	Country	Date
488,875	Great Britain	July 15, 1938

OTHER REFERENCES

Review of Scientific Instruments, vol. 8, No. 6, June 1947, "A Mass Spectrometer for Isotope and Gas Analysis" by Alfred O. Nier, pages 398–411.