United States Patent

Hull et al.

[15] **3,699,332**

[45] **Oct. 17, 1972**

[54] **MAGNETIC MASS SPECTROMETER WITH SHAPED, UNIFORMLY SATURATING MAGNETIC POLES**

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[73] Assignee: **Bell & Howell Company**, Chicago, Ill.

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[21] Appl. No.: **15,186**

[52] **U.S. Cl.**............................**250/41.9 ME,** 335/210
[51] **Int. Cl.**..**H01j 39/34**
[58] **Field of Search**........250/41.9 ME; 335/210, 211

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Assistant Examiner—C. E. Church
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[57] **ABSTRACT**

A magnetic mass spectrometer having a magnetic analyzing sector utilizing shaped magnet poles of a specific configuration so as to produce uniform magnetization of the pole material and constant flux distribution at all magnetic field strengths. The magnet poles are shaped such that the surfaces thereof conform to an exponential function. Magnetic shunts are located at a predetermined spacing from the entrance and exit end of the analyzing sector to locate the magnetic field boundary.

16 Claims, 10 Drawing Figures

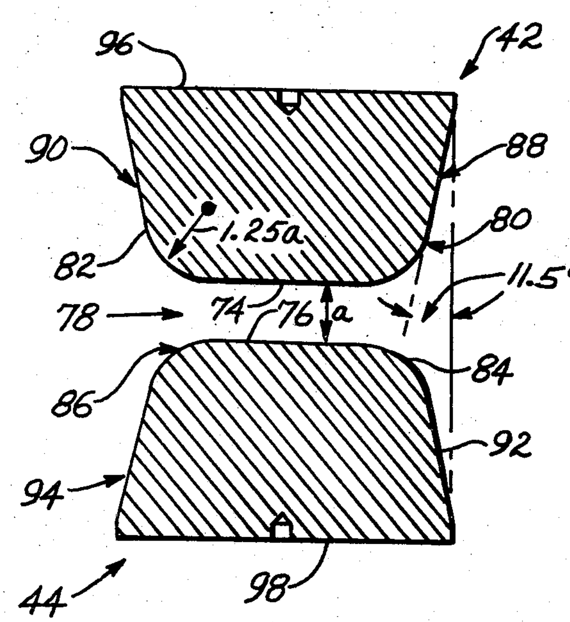

FIG_1

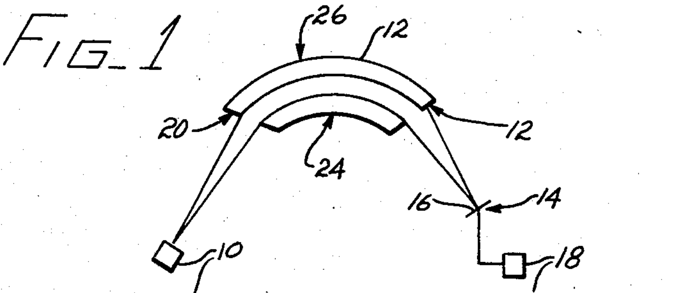

FIG_2

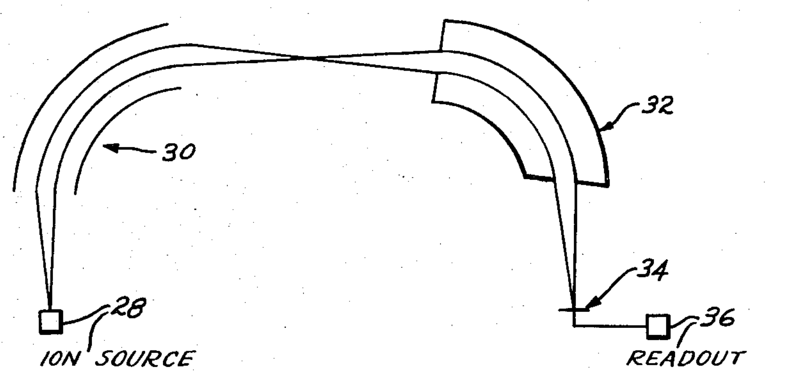

FIG_4

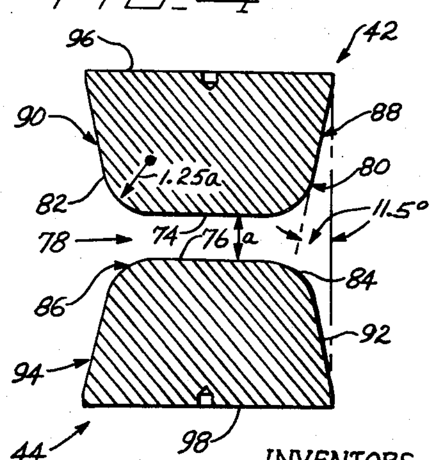

FIG_5

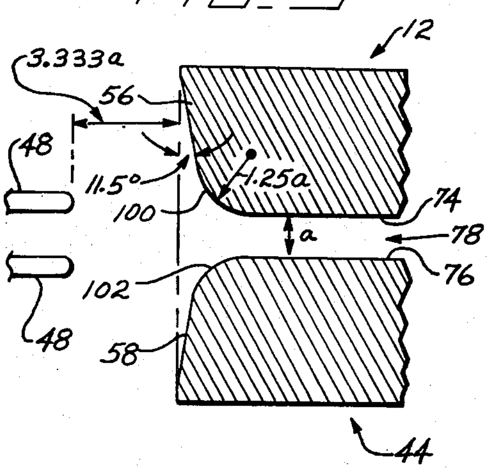

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FIG_3

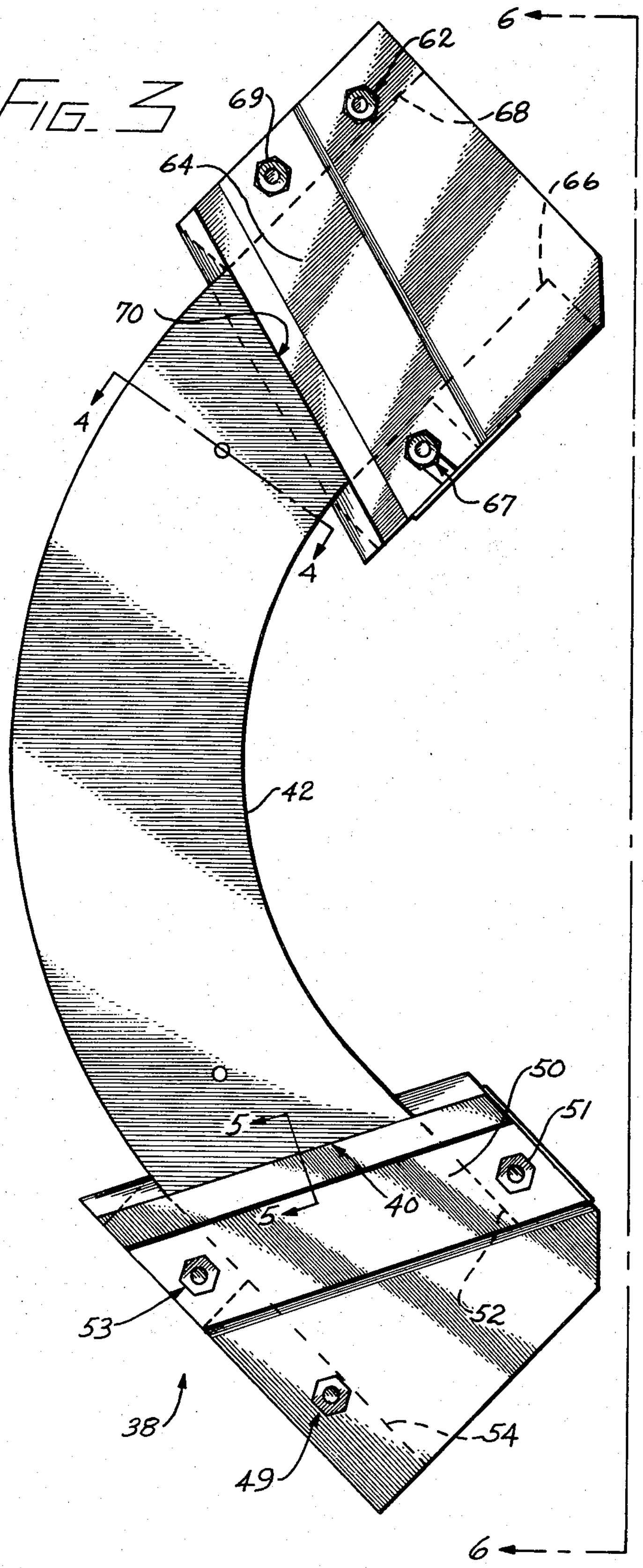


FIG_7A

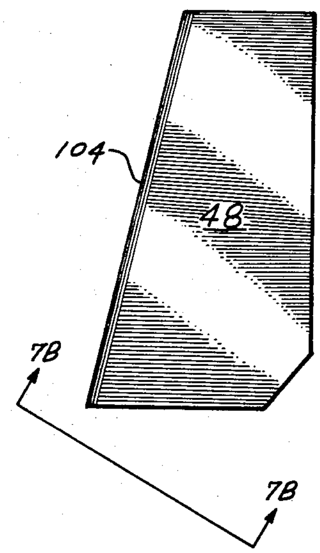


FIG_7B

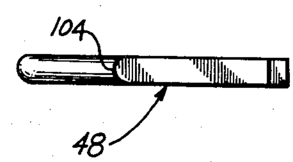
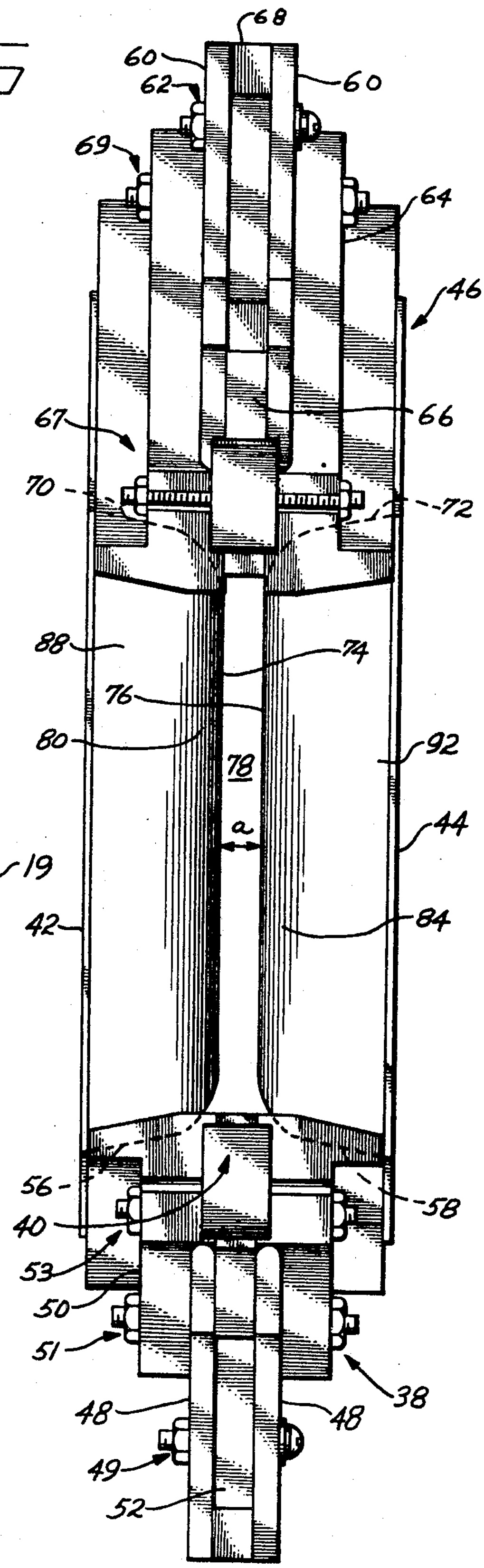


FIG. 6


68
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88
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76
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84
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56
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FIG. 9

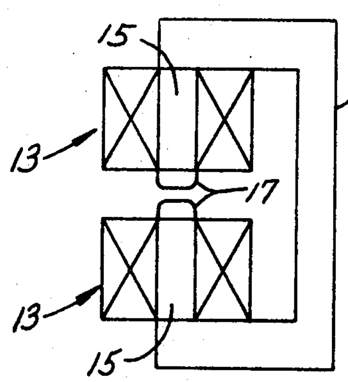
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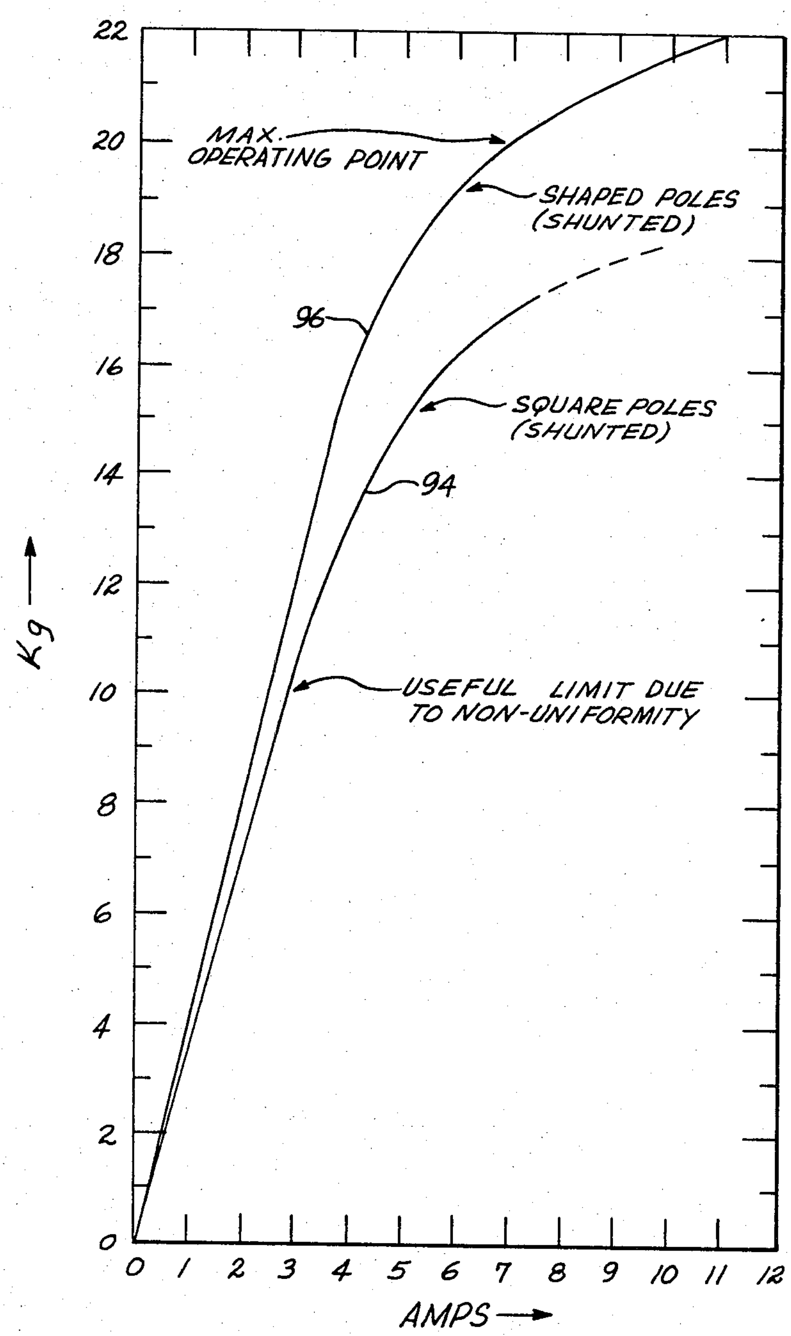
FIG_8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20
18
16
14
12
10
8
6
4
2
0
Kg
0 1 2 3 4 5 6 7 8 9 10 11 12
AMPS
MAX. OPERATING POINT
SHAPED POLES (SHUNTED)
96
SQUARE POLES (SHUNTED)
94
USEFUL LIMIT DUE TO NON-UNIFORMITY

MAGNETIC MASS SPECTROMETER WITH SHAPED, UNIFORMLY SATURATING MAGNETIC POLES

DESCRIPTION OF THE PRIOR ART

The present invention relates to magnetic momentum analyzers and in particular to positive ion mass spectrometers. Prior to relatively recent developments in the art, magnetic momentum analyzers have been characterized by a magnetic analyzing sector having poles with precise, sharply defined, usually square, pole faces.

The use of shaped, non-square pole pieces in magnetic momentum analyzers has been proposed as a way in which to combat distortions in the magnet flux distribution in the pole pieces and unpredictable aberrations in particle trajectory encountered by charged particles particularly at the entrance and exit ends of the magnet in such analyzers due to "edge effects" in the magnetic material. Specifically, a curvilinear shape corresponding to an exponential function first postulated for electric field generating electrodes has been proposed for the end and side faces of the pole pieces. The result of using such a shape is that magnetization of the magnetic material is uniform throughout material for all field strengths and without distortion particularly near the edges and corners of the pole pieces regardless of the magnetization level of the material. Such uniform magnetization means constant flux distribution at all field strengths and the elimination of end effects at saturation levels. In one instance the importance of this discovery has been recognized and utilized in a magnetic beam analyzer for measurement of the energy of nuclear particles to a heretofore unattainable degree of accuracy. As used in connection with the present discussion, the term "uniform magnetization" refers to the property of the magnetic material wherein the flux distribution of the magnetic field remains constant and uniform at all field strengths. This characteristic is also sometimes referred to as one in which the magnetic field saturates in a uniform manner.

In one specific version of exponentially shaped pole pieces the end and side edges adjacent the pole faces are rounded on a circular radius having a dimension which is a predetermined fraction (0.83) of the actual spacing between the pole pieces, i.e., the width of the magnetic gap. In addition, the end and side faces extending away from the rounded edges are provided with an outward taper relative to the pole faces, which taper forms an angle of approximately 5.7° with respect to a line erected perpendicularly to the pole face. Upon analysis, however, it has been found that the resultant pole shape obtained using these parameters is a poor approximation of the true theoretical exponential shape and that as a result distortion and non-uniformities of the magnetic field are still experienced.

To further improve the operation of charged particle analyzers, the use of field clamps, also called magnetic shunts, adjacent the end faces of analyzing sector magnets has also been proposed. The function of such shunts is to aid in producing a sharp cutoff between the region of zero field externally of the magnet and the region of magnetic field within the magnet. Such shunts also have the effect of eliminating the reversal of the magnetic field which often occurs in magnets at a distance removed from the magnetic gap.

The spacing of these shunts relative to the end faces of the magnet particularly with exponentially shaped poles has usually been established at a distance equal to the spacing between the pole pieces. Such spacing, however, has been found to result in a "loading" of the poles producing an "edge effect" like phenomenon at the end faces of the magnet which reintroduces distortions and thereby prevents design of an instrument of accurately predictable performance. While the benefits of utilizing exponentially shaped magnetic poles in charged particle analyzers have been recognized, at least to a limited degree, their application has been limited to use with energy analyzers. Thus, in general, instruments utilizing such magnets have been confined to use with particles of known mass or derivation.

SUMMARY OF THE PRESENT INVENTION

A new shape for the pole pieces and a new spacing for the magnetic shunts are provided by the present invention. In providing a new shape for the pole pieces, an accurate reproduction of the true theoretical exponential shape for the ends and sides of the pole pieces is accomplished with the resultant improvement in the uniformity of the flux distribution. At the same time, a considerably greater spacing is provided for the shunts than has heretofore been provided in prior art arrangements which reduces the loading effect due to the shunts to a negligible amount while retaining the benefit of precisely locating the magnetic field boundary.

A new magnetic mass spectrometer utilizing a magnet according to the present invention, one which operates on either the single or double focusing principle and having substantially improved operating characteristics is also provided. Inherent in the use of exponentially shaped poles in a variable magnetic field, double focusing mass spectrometer is the recognition that such an instrument possesses a fixed focal point and in conjunction with an electrostatic analyzer is capable of first order focus of energy and angular divergence with minimal higher order aberrations.

In one aspect the present invention provides a uniformly saturating magnet comprising a first pole half of a generally U-shaped configuration in both a transverse and longitudinal direction and a second pole half of a generally U-shaped cross-section in both a transverse and longitudinal direction spaced a predetermined distance from the first pole half. The two pole halves are aligned with the base portions of their U-shape facing each other in a parallel orientation. The side and end edges of the opposing base portions are rounded on a radius of approximately 1.25 times the distance between the pole halves and the arm portions of the U-shape are provided with an outward taper of a predetermined slope with respect to a perpendicular through the base portions. Electric coil means are also provided in magnetic field generating relation to the pole halves.

In another aspect the present invention provides an improved mass spectrometer comprising a source of ions, a detector of ions and a deflecting and focusing magnetic analyzing sector interposed between the ion source and ion detector along the path of ions from the source. The magnetic analyzing sector includes a pair of shaped pole pieces of a magnetic material, the pole pieces being spaced a predetermined distance apart and having a predetermined thickness and width, the shaping of the pole pieces being chosen such that the magnetic material magnetizes uniformly and the magnetic flux distribution in the magnetic material remains constant at all magnetic field strenghts. Means for varying the magnetic field in the magnetic analyzing sector for bringing ions of a predetermined mass into register at the detector are also provided.

In terms of ion optics, the elimination of magnetic distortion means that a mass analyzing instrument can now be designed in which all parameters are precisely determinable prior to actual instrument construction. A double focusing mass spectrometer according to the present invention utilizing shaped magnet pole pieces having magnetic shunts spaced at specified distances from the entrance and exit of the magnetic sector and an electrostatic analyzer (spherical or cylindrical) provides an instrument which has a focal point which is fixed with respect to both angular and energy deviations to first order and further one in which higher order aberrations are very small.

In addition to the preceding, a new property of exponentially shaped magnetic poles has been discovered, namely, that such poles have significantly lower magnetic reluctance compared to square poles of comparable size. In terms of operating characteristics this means that a shaped magnet according to the present invention can obtain substantially higher flux levels for a given amount of magnetic material and a given pole spacing in comparison with a magnet having square poles. The increase in flux density plus the elimination of edge effects at the corners of prior art square poles means that the operating range of such a magnet in a typical high resolution mass spectrometer can be doubled from 10 kilogauss to at least 20 kilogauss. Thus, an operator utilizing an instrument according to the present invention can obtain four times the mass range heretofore obtainable or a commensurate increase in resolution due to an ability to use four times the amount of accelerating voltage for an equivalent mass than heretofore possible. A corollary of this newly discovered property is that operating results comparable to a conventional high resolution square pole magnet instrument can now be obtained by means of an instrument utilizing a substantially smaller exponentially shaped magnet.

DESCRIPTION OF THE DRAWINGS

The features and advantages of the invention outlined above will be better understood by reference to the following figures in which:

FIG. 1 is a diagram of a single focusing mass spectrometer utilizing the magnet structure of the present invention;

FIG. 2 is a diagram of a double focusing mass spectrometer utilizing the magnet structure of the invention;

FIG. 3 is a plan view of a magnetic analyzing sector utilizing pole pieces according to the present invention;

FIG. 4 is a section view taken along line 4—4 of FIG. 3;

FIG. 5 is a section view taken along line 5—5 of FIG. 3;

FIG. 6 is a side elevational view taken along line 6—6 of FIG. 3;

FIG. 7A is a plan view of a shunt plate utilized with the magnetic analyzing sector of the present invention;

FIG. 7B is an elevational view of the shunt plate shown in FIG. 7A;

FIG. 8 is a graph illustrating the operating characteristics of a magnetic analyzing sector according to the prior art and according to the present invention; and

FIG. 9 is a schematic diagram of the pole pieces, core, yoke and electric coils according to the present invention.

DESCRIPTION OF A SPECIFIC EMBODIMENT

The present invention specifies the use of shaped pole pieces of a particular configuration as part of the electromagnet utilized in the magnetic momentum analyzer and further specifies an improved double focusing mass spectrometer utilizing such an electromagnet. A shorthand expression for describing pole pieces of the desired configuration is to refer to them as "Rowgowski" poles. Poles of this type have a geometry in which the edges and faces are shaped such that the outline or profile of such pole pieces follow or closely approximate an exponential function defined by a set of equations (see below) first proposed by W. Rowgowski for electric field generating electrodes. (*Archiv für Elecktro-technik*, Vol. 12, 1923, pp. 1–19).

While the applicability of the Rowgowski equations to pole pieces of electromagnets has been suggested previously, their use in magnetic momentum analyzers has been limited to instruments which are utilized in a fixed focus mode to make energy measurements of particles of known mass. The present invention specifies the provision of Rowgowski poles in positive ion mass spectrometers utilizing variable magnetic fields to produce a focus at a fixed point with respect to the exit end of the magnetic analyzing sector for ions of all masses. In addition, the shaped poles according to the present invention have an altered profile relative to prior art Rowgowski poles which produces a significantly more accurate approximation of the exponential functions defined by the Rowgowski equations.

The application of the invention to a single focusing mass spectrometer is shown in FIG. 1. In that figure a source of ions **10** is disposed at a point removed from a deflecting and focusing magnet in sector **12** according to the present invention and a detector **14** is located at a point removed from the exit end of the magnet and positioned at the focal point **16** of the magnet. Suitable electronics **18** are connected to detector **14** for providing the desired readout of the conditions at the detector, for example, the magnitude of the ion current incident thereon. A typical magnetic sector (FIG. 9) according to the present invention comprises a pair of electromagnetic coils **13** disposed in magnetic field generating relation to a pair of cores **15** and a pair of opposed, shaped pole pieces **17** of the Rowgowski exponential configuration. A yoke **19** completes the magnetic circuit between the cores and pole pieces. It is to be understood throughout the discussion of the present disclosure the indication that the pole pieces are of an exponential shape refers to a shape defined by the Rowgowski equations. In one embodiment of the invention a configuration is imparted to the entrance, exit, and side edges and faces of the magnet pole pieces as is shown in FIGS. 3, 4, 5 and 6. Providing such a shape ensures that the magnetic material magnetizes uniformly and that the flux distribution in the material remains constant at all magnetic field strengths. In general, the magnet of the present invention is applicable to the various known types of single focusing, magnetic mass spectrometers.

The present invention is also applicable to instruments generally referred to as double focusing mass spectrometers, i.e., analyzers that are capable of providing both an angular and an energy focus for heteroenergetic particles emitted by an ion source such as an electrical discharge source. A typical instrument is illustrated in FIG. 2 wherein a source of ions **28** is arranged to direct a particle beam at an electrostatic lens **30**, which may be of either cylindrical or spherical type, with the partially sorted particles emerging from lens **30** being thereafter directed toward a deflecting and focusing magnet in sector **32** according to the present invention. Particles of a predetermined mass thereafter emerge from sector **32** and are collected at detector **34** located at the point of angular and energy focus for the analyzer. The detector is in turn connected to suitable readout electronics **36**. As is typical of instruments of this type, a reversal of the positions of source **28** and detector **34** is also possible while still obtaining comparable operating results. The illustrations in FIGS. **1** and **2** are representative of several possible sector angles for the magnetic analyzer according to the present invention. As shown, the magnet in FIG. **1** occupies an angular sector of approximately 120°; the magnet in FIG. **2** occupies a sector of approximately 90°. As shown, the entrance and exit ends form various angles with the longitudinal axis of the sector. Configurations other than straight line configurations are also possible. The use of a magnet having Rowgowski shaped pole pieces is likewise applicable to mass analyzers of other angular sectors, for example, an 180° sector type of instrument.

A specific embodiment of a magnet pole assembly according to the present invention is depicted in FIGS. **3** and **6**. As shown therein the assembly comprises a pair of shaped, spaced pole pieces **42, 44** of a magnetic material, e.g., vacuum cast pure iron such as that marketed under the designation Vacuumet, and having a predetermined configuration and profile, an entrance shunt assembly **38** disposed adjacent the entrance end **40** of the pair of pole pieces, and an exit shunt assembly **46** located adjacent the exit end of the pair of pole pieces. Shunt assembly **38** includes a pair of relatively thin, flat plates **48** of a magnetic material, a shunt holder **50** of a non-magnetic material such as aluminum and a pair of shunt spacers **52, 54** located on opposite sides of assembly **38**. Each of said spacers includes a length of non-magnetic material such as aluminum approximately coextensive with the shunt holder in the longitudinal direction joined endwise to a length of magnetic material approximately coextensive with the magnetic shunt plates in the longitudinal direction. The magnetic material portion of the shunt spacers provide the means whereby the magnetic circuit between the shunt plates is completed while at the same time providing a central opening between the plates to permit the entry and exit of charged particles at the magnetic analyzing sector.

Spacer **52** is secured to holder **50** by fastening means **51**. Spacer **54** is secured to holder **50** by fastening means **53**. Shunt plates **48** are secured to spacer **54** by fastening means **49**. In a preferred embodiment the shunt assembly is attached to the ends of the pole pieces **42, 44** by an adhesive bond so as to not disturb the magnetic characteristics of the pole pieces. The faces of the shunt holder adjacent the poles have a mating taper to permit a flush fit between the face of the shunt holder and the end faces **56, 58** of pole pieces **42, 44**, respectively. The exit shunt assembly is similar in all respects to the entrance end shunt assembly and again comprises a pair of relatively thin plates of magnetic material **60** secured by suitable fastening means **62** to a non-magnetic shunt holder **64** with a pair of shunt spacers **66, 68** comprised of lengths of non-magnetic and magnetic material joined endwise extending between the shunt holder and the shunts on opposite sides of the assembly. Spacer **66** is secured to holder **64** by fastening means **67**. Spacer **68** is secured to holder **64** by fastening means **69**. Shunt assembly **46** is, as before, secured to the exit end faces **70, 72** of poles **42, 44** by an adhesive bond.

The specific configuration and geometry of the sides and ends of pole pieces **42, 44** are best described with reference to FIGS. 4 and 5, section views taken through specified portions of the magnetic pole shown in FIG. 3. In FIG. 4, a section view taken along line 4—4 of FIG. 3, pole pieces **42, 44** are shown disposed such that pole faces **74, 76** are disposed in a facing relationship across a gap **78** of a predetermined width, the dimension of which will be referred to as having a measurement of *a*. In contrast to conventional magnetic pole pieces whose faces are normally machined square, the corners **80, 82** of pole piece **42** and corners **84, 86** of pole piece **44** are rounded with a predetermined radius proportional to the gap spacing, a, with the curvature extending between the straight lines defining pole faces **74, 76** and the straight lines defining side faces **88, 90, 92, 94**, respectively. It will be noted that the side faces of both pole pieces taper outwardly with respect to the pole faces and have a predetermined slope. The overall thickness of pole pieces **42, 44**, as measured along a perpendicular extending through pole faces **74, 76** and back faces **96, 98**, as well as the width of the flat area on the pole faces between the curved edges, also bear a relation to overall performance of a magnet utilizing such poles.

The particular configuration of the end faces of pole pieces **42, 44** are illustrated by reference to FIG. **5**, a section view taken along line 5-5 of FIG. 3. Entrance end faces **56, 58** shown in FIG. **5** are also illustrative of the configuration of exit end faces **70, 72**, although said exit end faces are not specifically depicted in the drawing. As with the side corners, the end corners **100, 102** are rounded along an arc having a predetermined radius. End faces **56, 58** likewise have an outward taper of a predetermined slope relative to a perpendicular to pole faces **74, 76**.

Although first postulated for application to electrodes for creating a uniform electric field, the Rowgowski theory has been shown to be applicable to the shape of magnets used to create a uniform magnetic field. The generating mathematical expressions for the surfaces of the magnets according to the Rowgowski theory are

$$x=\frac{a}{\pi}\phi$$

$$y=\pm\frac{a}{\pi}\left(\frac{\pi}{2}+e^{\phi}\right)$$

where a is the minimum distance between the pole pieces (gap spacing) and ϕ is proportional to the magnetic flux between the pole pieces. These equations may be combined by eliminating ϕ to give

$$y=\pm\frac{a}{\pi}\left(\frac{\pi}{2}+e^{\pi x/a}\right)$$

In these equations y passes perpendicularly through the pole pieces and gap spacing and x is perpendicular to y, i.e., x and y are the abscissa and ordinate respectively. The foregoing expressions define a pair of infinite exponential surfaces which to a satisfactory degree are approximated by pole pieces having a finite thickness and width. When applied to a magnet of high permeability the Rowgowski formula yields a structure characterized by essentially uniform magnetization throughout the pole piece. In a presently preferred embodiment of the present invention, the exponential surfaces as defined by the Rowgowski equations above are approximated at the sides and ends of the pole pieces by two straight lines connected by a circular arc having a radius of 1.25*a*. The first straight line corresponds to the pole face of each pole piece. The second straight line corresponds to the side and end faces of the pole pieces and is connected to the arc such that the slope of the line corresponding to these side and end faces is 11.5°. To complete the surfaces of the pole pieces a smooth transition between adjacent side and end faces is imparted thereto. To satisfactorily approximate the infinite Rowgowski surfaces and thereby obtain the desired objectives of uniform magnetization of the magnetic material and the flux distribution which remains constant at all field strengths, the thickness of the pole pieces according to a presently preferred embodiment is at least 3.333*a* and the width of flat area of the pole faces is at least 2.5*a*. An exact replica of the Rowgowski exponential surface can be imparted to the pole pieces by means of a computer operated machining programmed to follow the Rowgowski equations.

In order to be able to mathematically define the ion optics in an analyzer having a uniform magnetic field produced by magnets having the Rowgowski exponential shape, it has been found useful to employ shunts of magnetic material located near the entrance and exit faces of the magnet poles in the region of the fringing fields created by such poles. The specific location of the magnetic shunts with respect to the end faces of the pole pieces is a particular part of the present invention. It has been found that location of the shunts too closely adjacent the end faces of the poles may exert a "loading" effect on the poles creating a mathematically unpredictable edge effect, similar to the distortion produced when the square corners of conventional magnet poles go into saturation. According to the present invention the spacing of the magnetic shunts is approximately a distance 3.333*a* from both the entrance and exit end faces of the magnet poles.

A typical magnetic shunt plate **48** according to the present invention is illustrated in FIGS. **7A** and **7B**. As shown therein shunt plate **48** is approximately trapezoidal in plan view and is provided with a rounded edge **104** along the edge of the shunt most closely approaching the end faces of the pole pieces. In keeping with the basic function of the magnetic shunts or clamps to produce a sharp cutoff of the magnetic field, i.e., to precisely locate the field boundary, the thickness of the plate is determined by the requirement that the shunt have sufficient permeance to accommodate the intercepted flux in the fringing field. By spacing the magnetic shunts of the present invention a distance approximately 3.333*a* from the end faces, the objective of a sharp cutoff of the field is achieved without at the same time introducing any distortion or other indeterminate factors. The shunts also eliminate the aberrational effect of the field reversion which often occurs at a relatively large distance away from the magnet particularly when the magnet yoke approaches or goes into saturation.

The improvement in performance in a small mass spectrometer utilizing shunted and shaped magnetic poles according to the present invention relative to the performance of a mass spectrometer of comparable size utilizing conventional shunted square poles is partially illustrated by reference to FIG. **8**, a graph in which field strength in kilogauss (kg) in a magnetic analyzing sector is plotted along the ordinate and current in an electromagnetic coil generating the magnetic field is plotted along the abscissa. Curve **94** illustrates the performance of a conventional mass spectrometer. Curve **96** illustrates performance of a mass spectrometer according to the present invention. In the conventional mass spectrometer the useful upper limit of the magnetic field is typically 10 kg because it is at that point along the curve that significant distortion is encountered due to saturation effects at the square edges of the magnet. Thus despite the fact that it is possible to obtain higher field strengths with a conventional configuration, the operating range of the instrument is limited to the field strength shown. Operation beyond this limit is essentially meaningless since the distortion created in the magnetic analyzing field is such as to reduce the resolving power of the instrument.

In contrast, in a mass spectrometer according to the present invention, the flux distribution in the magnetic analyzing sector remains uniform regardless of the field strengths created in the sector. In one practical embodiment of an analyzer according to the present invention, the upper limit or maximum operating point is established at 20 kg.

Other advantages of a mass analyzer having poles according to the present invention are utilization of the discovery that magnetic reluctance of such poles is less than that for square poles of a comparable size. This is primarily due to the fact that square poles must carry a larger amount of flux in a direction perpendicular to the gap flux in order to supply magnetic flux to the fringing field. Thus in a square pole magnet the iron saturates with less gap flux than with exponentially shaped magnet poles. In terms of practical results, at least a 20 percent increase in gap flux density is achieved by utilizing magnetic poles according to the present invention.

By extending the working range of the magnet used with a high resolution mass spectrometer from 10 kg with square poles to 20 kg with exponentially shaped poles, the doubling of the working field strength means the provision of a mass spectrometer with four times the mass range. Alternatively, it is now possible to obtain four times as high an accelerating voltage for an equivalent mass thereby obtaining a significant increase in resolving power for the analyzer. Still another alternative way in which to employ the advantage of the present invention is the provision of a magnet of a substantially reduced size producing commensurate reductions in the size and cost of an analyzer utilizing such a magnet while still obtaining the same results as obtainable with prior high resolution square pole mass spectrometer. To the user of instruments of this type the improvement provides an instrument which has greatly simplified operating characteristics making such an instrument available for use by personnel with little or no familiarity with mass spectrometers while at the same time achieving operating results in terms of resolution in excess of that heretofore obtainable.

What is claimed is:

1. A scanning mass spectrometer comprising:
a source of ions;
a detector of ions;
a deflecting and focusing magnetic analyzing sector interposed between the ion source and ion detector along the path of ions from the source, the magnetic analyzing sector including a pair of shaped pole pieces of a magnetic material, the pole pieces being spaced a predetermined distance apart and having a predetermined thickness and width, the shaping of said pole pieces being chosen such that the magnetic material magnetizes substantially uniformly and the magnetic flux distribution in the magnetic material remains substantially constant at all magnetic field strengths; and
means for varying the magnetic field in the magnetic analyzing sector for bringing ions of any one of a plurality of different predetermined masses into register at the detector.

2. A mass spectrometer according to claim 1 wherein the shape of the pole pieces is substantially defined by the expression

$$y=\pm\frac{a}{\pi}\left(\frac{\pi}{2}+e^{\pi x/a}\right)$$

where a is the minimum spacing between the pole pieces and
y is the ordinate axis passing perpendicularly through the pole pieces and gap spacing and x is the abscissa axis passing perpendicularly to the y axis.

3. A mass spectrometer according to Claim 1 wherein the pole pieces are provided with rounded edges and outwardly tapering faces at the ends and sides thereof, the edges being rounded to a radius approximately 1.25 times the pole pieces spacing distance, the faces having a slope of approximately 11.5° with respect to an axis passing perpendicularly through the pole pieces and gap spacing.

4. A mass spectrometer according to claim 3 including magnetic shunting means located adjacent the ends of the pole pieces, the spacing of the shunting means relative to the ends being chosen such that the condition of constant flux distribution in the magnetic field of the analyzing sector is not altered.

5. A mass spectrometer according to claim 4 wherein the shunting means are spaced from the ends of the pole pieces a distance approximately equal to 3.333 times the pole piece spacing.

6. A mass spectrometer according to claim 1 including magnetic shunting means located adjacent the ends of the pole pieces, the spacing of the shunting means relative to the ends being chosen such that the condition of substantially constant flux distribution in the magnetic field of the analyzing sector is not appreciably altered.

7. A mass spectrometer according to claim 6 wherein the shunting means are spaced from the ends of the pole pieces a distance approximately equal to 3.333 times the pole piece spacing.

8. A scanning double focusing mass spectrometer comprising:
a source of ions;
an electrostatic lens disposed along the path of ions from the source;
a deflecting and focusing magnet disposed along a path of ions from the source at a predetermined spacing from the lens, the focusing magnet having a pair of opposed shaped pole pieces of a magnetic material spaced a predetermined gap distance apart and having a predetermined thickness and width, the shaping of the pole pieces being such that the magnetic material of the pole pieces saturates substantially uniformly and the flux distribution in the magnetic material remains substantially constant at all magnetic field strengths;
a detector of ions disposed along the path of ions from the source located on the side of the magnet and lens opposite the source, the source, lens, magnet and detector being spaced and oriented relative to each other such that ions are focused on the detector for both angular divergence and energy divergence from the source; and
means for varying the strength of the magnetic field in the magnet for bringing ions of any one of a plurality of different predetermined masses into register at the detector.

9. A mass spectrometer according to claim 8 wherein the shape of the pole pieces is substantially defined by the expression

$$y=\pm\frac{a}{\pi}\left(\frac{\pi}{2}+e^{\pi x/a}\right)$$

where a is the minimum spacing between the pole pieces and
y is the ordinate axis passing perpendicularly through the pole pieces and gap spacing and x is the abscissa axis passing perpendicularly to the y axis.

10. A mass spectrometer according to claim 8 wherein the pole pieces are provided with rounded edges and outwardly tapering faces at the ends and sides thereof, the edges being rounded to a radius approximately **1.25** times the gap distance, the faces having a slope of approximately **11.5°** with respect to an axis passing perpendicularly through the pole pieces and gap spacing.

11. A mass spectrometer according to claim 10 including first magnetic shunting means located adjacent the pole pieces between the lens and the magnet; and
second magnetic shunting means located adjacent the pole pieces between the magnet and the detector, the spacing of the first and second shunting means relative to the pole pieces being chosen such that the constant flux distribution in the magnetic field of the analyzing sector is not altered.

12. A mass spectrometer according to claim 11 wherein the first and second shunting means are each spaced from the pole pieces a distance approximately equal to 3.333 times the gap distance.

13. A mass spectrometer according to claim 12 wherein the pole pieces are elongated in the direction of ion travel such that ions pass through an entrance and exit side of the pole pieces and move approximately parallel to the remaining sides of the pole pieces.

14. A mass spectrometer according to claim 13 wherein the thickness of the pole piece is at least about 3.333 times the gap distance, and the width of the pole pieces is at least about 2.50 times the gap distance.

15. A mass spectrometer according to claim 8 including first magnetic shunting means located adjacent the pole pieces between the lens and the magnet; and

second magnetic shunting means located adjacent the pole pieces between the magnet and the detector, the spacing of the first and second shunting means relative to the pole pieces being chosen such that the substantially constant flux distribution in the magnetic field of the analyzing sector is not appreciably altered.

16. A mass spectrometer according to claim 15 wherein the first and second shunting means are each spaced from the pole pieces a distance approximately equal to 3.333 times the gap distance.

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