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ELECTRO-MECHANICAL SCANNING VOLTAGE REGULATOR

Walter A. Morgan, Baytown, Tex., assignor, by mesne assignments, to Esso Research and Engineering Company, Elizabeth, N.J., a corporation of Delaware

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5 Claims. (Cl. 250—41.9)

This invention relates to mass spectrometers. More particularly, this invention relates to a new and improved method of scanning a mass spectrum of a sample.

The development of new applications and analytical techniques in the field of mass spectrometry has been very rapid. Many of these advances have created a need for improved instrument performance and have resulted in the development of new mechanical and electronic components for the mass spectrometer.

An important object of this invention is to provide a regulator which has a reproducible and essentially constant scanning rate throughout the mass spectrum. The need for this requirement has been brought about by the difficulty which has been experienced in determining the mass number of widely spaced peaks which are obtained under certain operating conditions. In the past, identification has been complicated by the fact that a given distance on a recording chart represents varying numbers of mass units depending upon which portion of the mass spectrum is being considered.

Another objective of this new regulator is that it provide a visual form of mass identification at all times.

My new invention provides the art with a new mass spectrometer which satisfies the foregoing objectives, as well as other objectives. Means are provided for focusing on the collector of the spectrometer ions having a mass to charge ratio which varies linearly with time. Thus, a given distance on a recording chart represents the same number of mass units regardless of what portion of the mass spectrum is being considered. Means are also provided for indicating visually the mass to charge ratio of ions impinging upon the collector at any time.

A better understanding of the invention, as well as its many advantages, may be had by reference to the following detailed description and drawings, in which:

Fig. 1 is a diagram of a simplified mass spectrometer equipped with my invention; and

Fig. 2 is a graphical representation useful in explaining the advantages of my invention over the conventional devices for performing mass spectrometry operations.

Referring to Fig. 1, a mass spectrometer is shown including a curved analyzer 10 having an exit slit 11. The spectrometer may be used for determining the mass to charge ratio of ionized particles produced from two samples. If the sample is gaseous, it is introduced into the ionization chamber 12 through a sample inlet 13.

Means are provided for accelerating the ions through slit 14 and to direct the ions through the analyzer 10 toward the exit slit 11 and ion collector 15. The accelerated ions are then separated into a plurality of homogeneous ion beams by a magnetic field provided by a magnet adjacent the analyzer 10. The magnet is not shown for purposes of simplicity. Each homogeneous ion beam consists of ions having a particular mass to charge ratio. With a particular voltage applied across the ionization chamber, an ion beam having a particular mass to charge ratio can be made to pass through the exit slit 11 and impinge upon ion collector 15. By changing

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the voltage across the ionization chamber, an ion beam having a different mass to charge ratio passes through the exit slit 11 to be detected by ion collector 15. Therefore, by continuously varying the voltage across the ionization chamber 12, the ion beams can be made to successively pass through the exit slit 11 with continuously increasing or decreasing mass to charge ratios, i.e., the mass spectrum of the ionized molecules contained in the sample can be scanned. The ions impinging upon the ion collector 15 are amplified and recorded by the electrometer amplifying and recording apparatus 22.

The electrical circuitry of my new mass spectrometer includes a variable D.C. voltage supply 23 which supplies a voltage across a main circuit, including load resistance R_L , to the ionization chamber 12. An impedance means is connected across the main circuit. The impedance means consists of resistors R_1 and R_2 . Though two resistors are shown, it is to be understood that if desired, a single resistor may be used.

An electronic tube 24 having a cathode 25, grid 26, and plate 27, is also connected across the main circuit.

Means are provided for applying a voltage to the grid 26 of the electronic tube to focus on the ion collector 15 at any instant ions having a mass to charge ratio which varies linearly at a constant rate with respect to time. The circuit for causing this linear variation at a constant rate may be a feed-back circuit including a wiper arm 28 in contact with the resistance R_2 . The feed-back circuit also includes a reference voltage such as the battery E. The difference in voltage between that of the wiper arm 28 and the reference voltage E is applied to an amplifying system represented by the numeral 29. The output from the amplifying system 29 is applied to the grid 26 of electronic tube 24. Hence, it can be seen that the voltage applied to the grid 26 of tube 24 is representative of the difference in voltage between that of the wiper arm and the reference voltage.

A synchronous motor 30 may be directly coupled to the wiper arm 28 to move the wiper arm at a constant rate. The synchronous motor 30 is also connected to a digital dial 31 for indicating directly the mass to charge ratio of the ions being focused on the collector at any particular time.

It can be shown that the voltage applied to the ion source using my new voltage regulating system produces the desired linearly varying mass to charge ratio at a constant rate at the ion collector. The input to the amplifier 29 is E_y where

$$E_y = V \frac{R}{R_1 + R_2} - E = V \left[\frac{R_0 + rt}{R_1 + R_2} \right] - E$$

where:

R =resistance from the wiper arm to ground= $R_0 + rt$

R_0 =resistance from the wiper arm to ground at time $t=0$

r =rate of change of resistance in ohms per second due to the rotation of the potentiometer shaft at constant angular speed.

t =time in seconds

$R_1 + R_2$ =total resistance.

Resistance R_L and the combination of resistances R_1 and R_2 are very large compared to the plate resistance of the electronic tube 24. Hence, to a close approximation:

$$V = E_y A g_m r_p$$

where:

V =Output voltage from the regulator

A =The voltage gain of the amplifier

g_m =The mutual conductance of the shunt regulator tube

r_p =The plate resistance of the shunt regulator tube

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Combining the above two equations and solving for V:

$$(3) \quad V = \frac{E A g_m r_p}{\frac{(R_0 + r t) A g_m r_p}{R_1 + R_2} - 1}$$

Now, since

$$\frac{(R_0 + r t) A g_m r_p}{R_1 + R_2}$$

is much greater than 1,

$$(4) \quad V = E \left[\frac{R_1 + R_2}{R_0 + r t} \right]$$

This is the output voltage equation for the scanning voltage regulator.

What we are really interested in is the manner in which ions of varying mass to charge ratios are brought to focus when the regulators are used in a mass spectrometer. The fundamental equation of ion optics for a mass spectrometer is:

$$(5) \quad M V = 4.82 \times 10^{-5} B^2 r^2$$

where:

M=mass to charge ratio of the ions being brought to focus at the collector

V=the ion accelerating voltage in volts

B=the magnetic field strength in gauss

r=the radius of curvature in centimeters.

Since for a given machine the radius of curvature is fixed and for a particular analysis the magnetic field strength is held constant, we can simplify the equation to read:

$$M = \frac{K}{V}$$

where $K = 4.82 \times 10^{-5} B^2 r^2$

If we substitute the value of V obtained for the voltage regulator into this equation, we obtain:

$$(6) \quad M = \frac{K R_0}{E(R_1 + R_2)} + \frac{K r t}{E(R_1 + R_2)}$$

However, when $t=0$

(7)

$$\frac{K R_0}{E(R_1 + R_2)} = M_0 = \text{mass to charge ratio of the ions in focus at time } t=0$$

Therefore,

$$(8) \quad M = M_0 + \frac{K r t}{E(R_1 + R_2)}$$

And

$$(9) \quad \frac{dM}{dt} = \frac{K r}{E(R_1 + R_2)} = \text{a constant}$$

The last two equations above show that the mass to charge ratio of the ions being brought to focus at any instant varies linearly with time and that the scanning rate for my new regulator is constant throughout the entire mass spectrum. In order to demonstrate how the regulator provides some form of visual mass identification at all times, Equation 6 above can be rewritten with the terms grouped:

$$(10) \quad M = K \frac{(R_0 + r t)}{E(R_1 + R_2)}$$

However, we previously defined $R = R_0 + r t$; therefore:

$$(11) \quad M = \frac{K R}{E(R_1 + R_2)}$$

In other words, the mass to charge ratio of the ions being brought to focus in the mass spectrometer is linearly related to the resistance from the wiper arm to ground.

Hence, in order to determine the mass number it is only

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necessary to know this resistance. For a linear potentiometer:

$$R = k \theta$$

where:

5 k =the number of ohms per degree of wiper arm rotation
 θ =the number of degrees of wiper arm rotation from the condition of zero ohms

Hence

$$10 \quad (12) \quad M = \left[\frac{K k}{E(R_1 + R_2)} \right] \theta$$

Since " θ " is a mechanical quantity, it can be measured quite simply and accurately by means of a rotational counter or dial which is attached to the potentiometer shaft.

Fig. 2 is a graphical representation comparing the operation of a conventional "RC" type regulator with my new regulator. In the RC regulator, the mass of the collected ions is not linear with time. Also, in the RC type regulator, the scanning rate varies linearly with mass number. Line 40 represents the curve using the RC type regulator. From looking at Fig. 2, and particularly line 40, it can be seen that

$$25 \quad \frac{dM}{dt}$$

increases at the higher mass numbers. Hence, the peaks recorded on a chart are closer together than at the lower mass numbers, making them much more difficult to distinguish from one another.

Line 41 represents the curve obtained using my new regulator. It is seen that the

$$35 \quad \frac{dM}{dt}$$

of my new regulator remains constant throughout the mass spectrum. Hence, the peaks recorded on the recording chart or other recording means are equally spaced apart throughout the entire mass spectrum, making them much more easily interpreted.

In operation, the sample to be analyzed, such as a hydrocarbon in vapor phase, is admitted through sample inlet 13 in the ionizing chamber 12. The vapor is ionized in the ionization chamber. The voltage V is varied continuously to focus on the collector ions having a mass to charge ratio which varies linearly at a constant rate with time and recorded. If desired, the motor can be stopped at any particular point to determine or investigate a specific mass to charge ratio of ions constituting part of the sample. The actual mass to charge ratio being investigated will be indicated on the digital dial 31. Hence, my invention provides not only an improved scanning voltage regulator, but also provides a way for investigating ions having a particular mass to charge ratio, and easily identifying the mass to charge ratio being investigated.

I claim:

1. In a mass spectrometer having means for converting molecules into ions, an analyzer, a collector, means for accelerating the ions and directing the ions through the analyzer toward the collector, and means for producing a field in the analyzer to separate the ions according to their mass to charge ratio, the improvement of: a main circuit for feeding a voltage to the means for accelerating the ions; resistors connected across the main circuit; an electronic tube having a cathode, grid, and plate connected across the main circuit; and a feedback circuit including a wiper arm in contact with the resistors and a battery electrically associated with the wiper arm and the grid of the electronic tube for applying a voltage to the grid of the electronic tube and means for moving said wiper arm at a constant rate to focus on the collector, ions having a mass to charge ratio which varies linearly at a constant rate with time.

2. A mass spectrometer in accordance with claim 1

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wherein a motor moves the wiper arm at a constant rate and also moves a digital indicating means to directly indicate the mass to charge ratio of ions being focused on the collector.

3. In a mass spectrometer having means for converting molecules into ions, an analyzer, a collector, means for accelerating the ions and directing the ions through the analyzer toward the collector, and means for producing a field in the analyzer to separate the ions according to their mass to charge ratio, the improvement of: a main circuit for feeding a voltage to the means for accelerating the ions; resistors connected across the main circuit; an electronic tube having a cathode, grid, and plate connected across the main circuit; an amplifying system with its output being fed to the grid of the electronic tube; a wiper arm in contact with the resistors and a reference voltage source across the wiper arm and amplifying system for applying a voltage to the amplifying system and means for moving the wiper arm at a constant rate whereby ions can be focused on the collector having a mass to charge ratio which varies linearly at a constant rate with time.

4. In a mass spectrometer having means for converting molecules into ions, an analyzer, a collector, means for

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accelerating the ions and directing the ions through the analyzer toward the collector, and means for producing a field in the analyzer to separate the ions according to their mass to charge ratio, the improvement of: a main circuit for feeding a voltage to the means for accelerating the ions; an impedance means connected across the main circuit; an electronic tube having a cathode, grid, and plate connected across the main circuit; a feedback circuit for taking a voltage from said impedance means and feeding said voltage to the grid of the electronic tube; said feedback circuit including a voltage source; and means for varying the voltage taken from the impedance means in a manner such that ions are focused on the collector having a mass to charge ratio which varies linearly at a constant rate with time.

5. A mass spectrometer in accordance with claim 4 wherein the impedance means are resistors.

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