

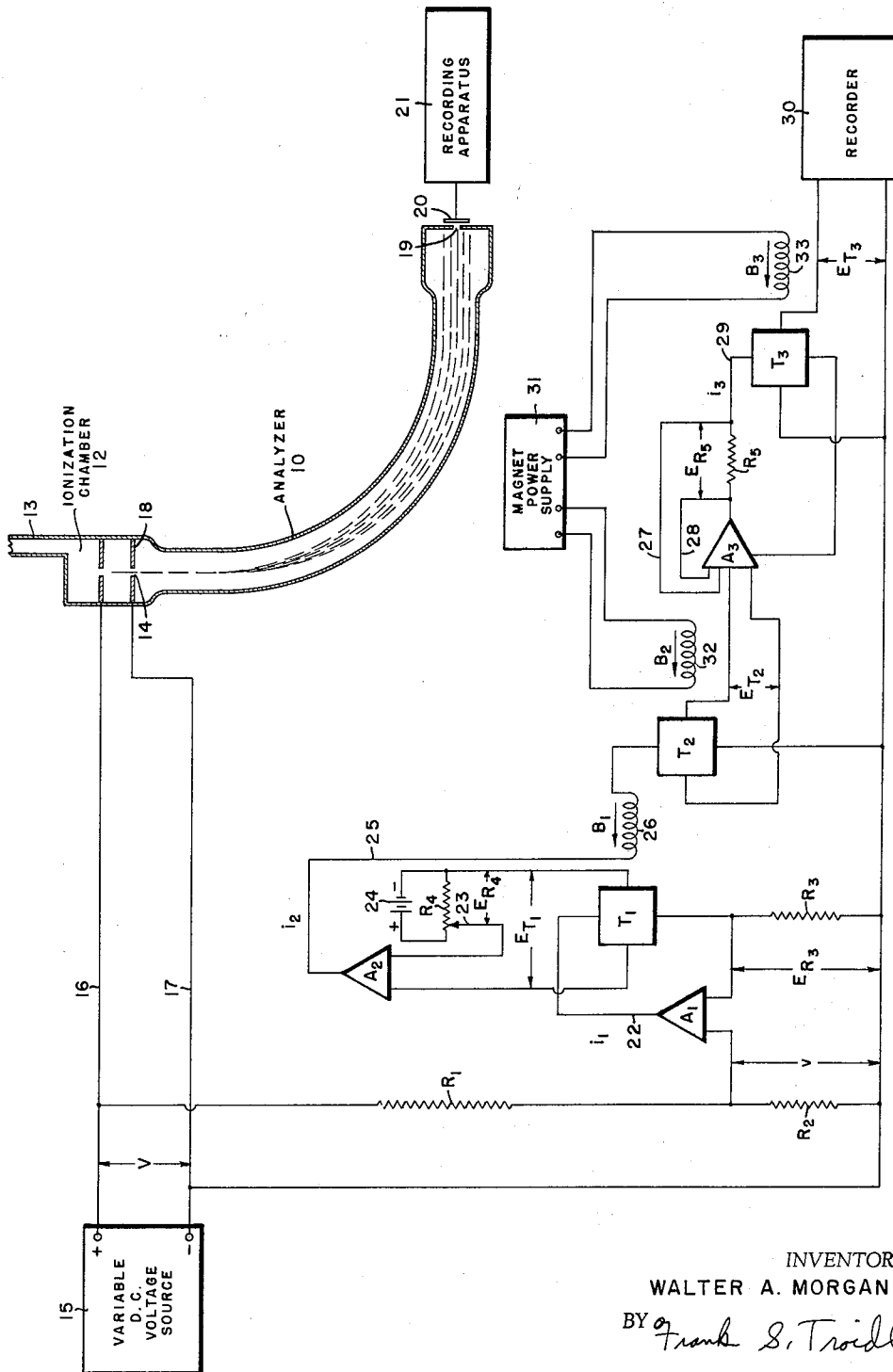
Sept. 10, 1963

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3,103,582

AUTOMATIC COMPUTER FOR USE WITH MASS SPECTROMETERS

Filed Nov. 24, 1961



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1

3,103,582

AUTOMATIC COMPUTER FOR USE WITH MASS SPECTROMETERS

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Filed Nov. 24, 1961, Ser. No. 154,591
3 Claims. (Cl. 235-194)

This invention relates to computers in general and more particularly to a system for use with a mass spectrometer.

One method of determining the chemical or elemental composition of a material as well as the relative abundances of the various materials in the sample is by means of a mass spectrometer. In a mass spectrometer, the material to be analyzed is ionized, accelerated by an electrostatic field and resolved into homogeneous ion beams by means of a magnetic field. Each homogeneous beam contains ions having a single mass to charge ratio. By varying the strength of the electrostatic field used to accelerate the ionized particles, ion beams of various mass to charge ratio can be brought to focus on the ion collector and their relative intensities determined.

There has long been a need for automatically determining the mass to charge ratio of the ions brought to focus at the collector of a mass spectrometer under varying conditions of accelerating voltage and magnetic field strength. The invention to be described herein satisfies this long-felt need. The invention automatically and continuously measures the ion acceleration voltage and the magnetic field strength in the mass analyzer section of the spectrometer and produces an output voltage directly proportional to the mass to charge ratio of the ions brought to focus at the collector.

A better understanding of the invention, as well as its many advantages, may be had by reference to the following detailed description and single FIGURE which is a diagram of a simplified mass spectrometer equipped with the computing system of my invention.

Referring to the drawing, a mass spectrometer is shown including an analyzer 10. The material to be analyzed, such as a gaseous hydrocarbon, is admitted into the ionization chamber 12 by means of an inlet, such as gas inlet 13. The gaseous molecules in ionization chamber 12 are ionized in the ionization chamber 12.

An electrostatic field impressing electrical circuit is provided for accelerating the ionized particles through exit slit 14. This circuit includes a variable D.C. voltage source 15 which feeds a voltage through lines 16 and 17 to apply a difference in potential V between the chamber 12 and accelerating electrode 18.

After the ionized particles have accelerated, they are resolved into separate homogeneous beams according to their mass to charge ratio by means of a magnetic field produced between the poles of an electromagnet (not shown). Those ions which pass through the slit 19 impinge on the collector electrode 20. The current produced by the ions impinging on the collector electrode 20 is measured by a recording apparatus 21.

The equation which describes the ion optics of a mass spectrometer such as that shown in the figure is:

$$(1) \quad M = (4.82 \times 10^{-5} r^2) \frac{B^2}{V}$$

where

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

V =the ion accelerating voltage

B =the magnetic field strength in gauss

r =the radius of curvature in centimeters

2

Since for a given mass spectrometer the radius of curvature " r " is fixed once the spectrometer is constructed, the above Equation 1 can be expressed as:

$$(2) \quad M = k \left(\frac{B^2}{V} \right)$$

where

$$k = 4.82 \times 10^{-5} r^2$$

The remainder of the electrical system shown in the figure is used to solve Equation 2 and produce an output voltage proportional to the mass to charge ratio of the ions impinging upon electrode 20.

The resistor R_1 and the resistor R_2 form a voltage divider connected across the ion accelerating voltage supply 15. A voltage v proportional to the ion accelerating voltage V is obtained across resistor R_2 .

$$(3) \quad v = K_4 V$$

where K_4 is a constant

A second voltage E_{R_3} is obtained across the resistor R_3 and compared to the voltage v by the amplifier A_1 . The output current, i_1 , from amplifier A_1 is fed to a transducer T_1 through line 22.

$$(4) \quad i_1 = G_1 (v - E_{R_3})$$

where G_1 is the gain of the amplifier A_1 expressed in amps. per volt.

The current, i_1 , passes through transducer T_1 and resistor R_3 .

Consequently:

$$(5) \quad E_{R_3} = i_1 R_3$$

Substituting Equation 5 in Equation 4 and solving for i_1 yields:

$$(6) \quad i_1 = \frac{G_1 v}{1 + G_1 R_3}$$

Since the gain G_1 of amplifier A_1 can be made very large, $G_1 R_3 \gg 1$ and $1 + G_1 R_3 \approx G_1 R_3$.

Therefore:

$$(7) \quad i_1 = \frac{v}{R_3}$$

Transducer T_1 is what is known as a Hall effect transducer. This transducer is made from a semiconductor material such as indium arsenide. When such a material is placed in a magnetic field and a current is made to flow through the semiconductor in a direction perpendicular to a magnetic field, a voltage is produced across the semiconductor along an axis normal to both the magnetic field and the direction of current flow. The equation describing this effect is:

$$(8) \quad E_T = K i B$$

where

E_T =the output voltage from the transducer in volts

i =the current through the transducer in amps.

B =the magnetic field strength in gauss

K =a proportionality constant with the units volts per amp. per gauss

The output current, i_2 , from a second amplifier A_2 is equal to:

$$(9) \quad i_2 = G_2 (E_{R_4} - E_{T_1})$$

where E_{R_4} is a constant potential obtained from a tap 23 in contact with the resistor R_4 connected across a battery 24 to form a potentiometer.

$$(10) \quad E_{T_1} = K_1 i_1 B_1$$

The output current, i_2 , from amplifier A_2 is fed through line 25 to a solenoid 26. This solenoid may be an air

core solenoid. The magnetic flux B_1 is produced by the current, i_2 , passing through the windings of the air core solenoid 26. The solenoid 26 is in close proximity to transducer T_1 so that the magnetic flux produced by the solenoid passes through transducer T_1 .

Therefore:

$$(11) \quad B_1 = K_N i_2$$

where

B_1 = the magnetic field strength in gauss at T_1

i_2 = the current through coil 26 in amps.

K_N = a proportionality constant with the units gauss per amp.

Combining Equations 10 and 11:

$$(12) \quad E_{T_1} = K_1 K_N i_1 i_2$$

Substituting Equation 12 in 9 and solving for i_2 :

$$(13) \quad i_2 = \frac{G_2 E_{R_4}}{1 + G_2 K_1 K_N i_1}$$

Since the gain G_2 of amplifier A_2 can be made very large, $G_2 K_1 K_N i_1 \gg 1$ and $1 + G_2 K_1 K_N i_1 \approx G_2 K_1 K_N i_1$.

Therefore:

$$(14) \quad i_2 = \frac{E_{R_4}}{K_1 K_N i_1}$$

Substituting Equations 3 and 7 in 14:

$$(15) \quad i_2 = \frac{R_2 E_{R_4}}{K_1 K_4 K_N V}$$

From an examination of Equation 15, it can be seen that the current, i_2 , through line 25 and coil 26 is inversely proportional to the ion accelerating voltage V .

The current, i_2 , is fed through the coil 26 to a second Hall effect transducer T_2 . A differential amplifier A_3 is connected between the transducer T_2 and Hall effect transducer T_3 . A resistor R_5 is connected in the output of the differential amplifier A_3 .

A feedback circuit consisting of lines 27 and 28 connected across resistor R_5 is used to conduct the voltage across the resistor R_5 back to the differential amplifier A_3 . The output current, i_3 , from the differential amplifier A_3 is conducted through line 29 to the transducer T_3 .

The current in line 29 which flows through transducer T_3 is:

$$(16) \quad i_3 = G_3 (E_{T_2} - E_{R_5})$$

where

$$(17) \quad E_{R_5} = i_3 R_5$$

$$(18) \quad E_{T_2} = K_2 i_2 B_2$$

Substituting Equations 17 and 18 in 16 and solving for i_3 yields:

$$(19) \quad i_3 = \frac{G_3 K_2 i_2 B_2}{1 + G_3 R_5}$$

Since the gain G_3 of amplifier A_3 can be made very large, $G_3 R_5 \gg 1$ and $1 + G_3 R_5 \approx G_3 R_5$.

Therefore:

$$(20) \quad i_3 = \frac{K_2 i_2 B_2}{R_5}$$

The output voltage from the computer E_{T_3} equals:

$$(21) \quad E_{T_3} = K_3 i_3 B_3$$

Substituting Equation 20 in 21 yields:

$$(22) \quad E_{T_3} = \frac{K_2 K_3 i_2 B_2 B_3}{R_5}$$

Now the Hall effect transducers T_2 and T_3 are mounted between the pole faces of the mass spectrometer analyzer magnet and in close proximity to each other and the analyzer section of the mass spectrometer tube.

Therefore:

$$(23) \quad B_2 = B_3 = B$$

Substituting Equations 15 and 23 in 22 yields:

$$(24) \quad E_{T_3} = \left[\frac{R_2 K_2 K_3 E_{R_4}}{R_5 K_1 K_4 K_N} \right] \frac{B^3}{V}$$

$$(25) \quad \text{Defining } k_1 = \frac{R_2 K_2 K_3 E_{R_4}}{R_5 K_1 K_4 K_N}$$

$$(26) \quad E_{T_3} = k_1 \left(\frac{B^3}{V} \right)$$

Dividing Equation 26 by 2 yields:

$$(27) \quad E_{T_3} = \left(\frac{k_1}{k} \right) M$$

where

E_{T_3} = output voltage from the computer

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

$k = 4.82 \times 10^{-5} r^2 = \text{a constant}$

$$k_1 = \frac{R_2 K_2 K_3 E_{R_4}}{R_5 K_1 K_4 K_N} = \text{a constant}$$

Thus, this computing system which is primarily for use with a mass spectrometer automatically produces a voltage E_{T_3} which is proportional to the mass to charge ratio of the ions brought to focus at the collector 20. The voltage E_{T_3} can be measured with a recorder 30 or digital voltmeter.

It is obvious that the computing system shown herein has applicability for computing operations other than in the mass spectrometer system shown. For example, a variable function Y can be multiplied by a second variable Z , with the product divided by a third variable X . This could be done by providing a voltage across resistor R_2 proportional in magnitude to X . The magnet power supply 31 can be removed. Then a current proportional in magnitude to Y can be fed to coil 32 and a current proportional to Z fed to coil 33.

The voltage fed to the recorder 30 would then be equal to:

$$E_{T_3} = k_1 \left(\frac{YZ}{X} \right)$$

I claim:

1. A computer for dividing a first variable by a second variable comprising: means for obtaining a first current proportional to the magnitude of the second variable; means responsive to said first current for obtaining a second current inversely proportional to the second variable and including a solenoid, and a first Hall effect transducer in close proximity to said solenoid, said first current being fed through the first Hall effect transducer and said second current being fed through said solenoid; and means for obtaining a voltage proportional to the first variable divided by the second variable including a second Hall effect transducer connected to said solenoid, and a magnetic flux generating member for generating a magnetic flux proportional to the magnitude of said first variable, said second Hall effect transducer being in close proximity to the magnetic flux generating member.

2. A computer in accordance with claim 1 wherein said means for obtaining a first current proportional to the magnitude of the second variable includes: a first resistor for obtaining a voltage proportional to the magnitude of the second variable, a differential amplifier, and a second resistor, the differential amplifier being adapted to compare the voltage across the first resistor and the voltage across the second resistor and generate a current proportional to the difference in said voltages, said current being fed through the second resistor.

3. A computer for multiplying a first variable by a second variable comprising: means for producing a voltage

5

proportional to the first variable including a first Hall effect transducer and a first magnetic flux generating member in close proximity to said first Hall effect transducer, said first magnetic flux generating member being adapted to generate a flux proportional to the magnitude of the first variable; a second Hall effect transducer and a second magnetic flux generating member in close proximity to said second Hall effect transducer, said second magnetic flux generating member being adapted to generate a flux proportional to the magnitude of the second variable; a differential amplifier electrically connected be-

5

tween said first and second Hall effect transducers; a resistor in the output of the differential amplifier and a feedback circuit for feeding the voltage across the resistor in said differential amplifier circuit back to the differential amplifier, the output of said differential amplifier being fed to said second Hall effect transducer.

6

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