NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO
ATTN OF:

March 27, 1971

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures contained in the Code GP to Code USI memorandum on this subject, dated June 8, 1970, the attached NASA-owned U.S. patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,340,395

Corporate Source : California Institute of Technology

Supplementary Corporate Source : Jet Propulsion Laboratory

NASA Patent Case No.: XNP-01056

Please note that this patent covers an invention made by an employee of a NASA contractor. Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of. . . ."

Gayle Parker

Enclosure:
Copy of Patent

N71-23041

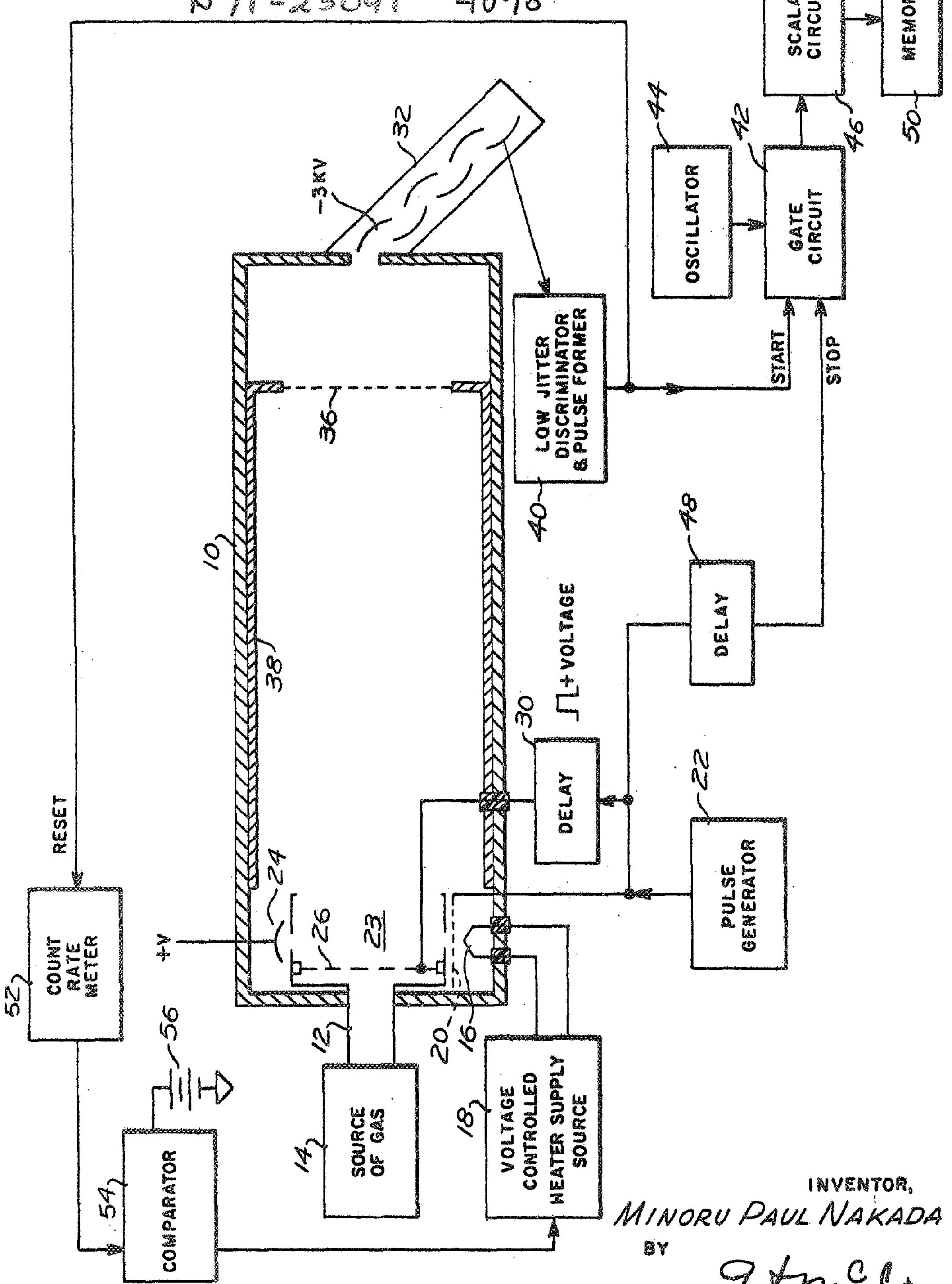
Sept. 5, 1967 JAMES E. WEBB 3,340,395

ADMINISTRATOR OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TIME-OF-FLIGHT MASS SPECTROMETER WITH FEEDBACK MEANS FROM THE DETECTOR TO THE LOW SOURCE AND A SPECIFIC COUNTER

Filed June 22, 1964

N71-23041 4070



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BY

[signature]

ATTORNEY

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United States Patent Office 3,340,395
Patented Sept. 5, 1967

3,340,395

TIME-OF-FLIGHT MASS SPECTROMETER WITH FEEDBACK MEANS FROM THE DETECTOR TO THE LOW SOURCE AND A SPECIFIC COUNTER

James E. Webb, Administrator of the National Aeronautics and Space Administration, with respect to an invention of Minoru Paul Nakada

Filed June 22, 1964, Ser. No. 377,146
7 Claims. (Cl. 250—41.9)

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 U.S.C. 2457).

This invention relates to mass spectrometers and more particularly to improvements in time-of-flight mass spectrometers.

A time-of-flight mass spectrometer is an instrument which measures the various types of proportions of gas in a sample. At present, this is done by ionizing portions of the gas sample, accelerating the resulting bunch of ions through a certain potential, and measuring the time required for the various types of ions to reach a detector. The heavier the ion, the more time it takes to reach the detector. Typically, the detector is an oscilloscope. A pulse of current which accelerates the ions towards the detector also initiates the horizontal scan of the oscilloscope. As the ions reach the detector, they produce a current which controls the vertical scan of the oscilloscope. The greater the number of ions in any instant, the greater the vertical displacement on the oscilloscope. The oscilloscope screen is then a graph of relative abundance versus mass number.

When the gases under very low pressure, such as the pressures expected to exist in the lunar atmosphere, are to be analyzed, a technique of individual ion counting is necessary. The reason for this is that at very low pressures it is difficult to obtain a large number of ions. A large number of ions are needed to be sure of including the same proportion of each mass number as is counted in the entire gas sample. Therefore, an oscilloscope cannot be employed in the manner described when gases under very low pressures are to be measured.

An object of this invention is to provide a mass spectrometer which can measure or analyze gases at low pressures. Another object of this invention is the provision of a mass spectrometer that can measure the time-of-flight of a single gas molecule at a time. Another object of this invention is to provide a time-of-flight mass spectrometer in which the abundance of each component gas may easily be determined by measuring the flight time of only one ion at a time. Yet another object of the present invention is to provide a new and improved low pressure mass spectrometer.

These and other objects of the present invention may be achieved in an arrangement wherein the number of ionizing electrons which are used to create ions are controlled so that substantially one ion at a time will be accelerated through the tube of the instrument. This ion, after the flight through the tube, is employed to gate an oscillator which is ungated at a predetermined time after the initial ion was created. Thus, the number of cycles of the oscillator between gating and ungating indicates the length of flight time.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawing which is a partial sche-

matic, partial block diagram view of an embodiment of the invention.

Referring now to the drawing, a mass spectrometer, in accordance with this invention, comprises a tube 10 having a gas inlet 12 at one end thereof. A source of the gas 14 to be measured is connected to the gas inlet tube 12. In a lunar environment or other low gas pressure environment, the atmosphere would replace the source of gas 14.

At the gas inlet end of the tube, there is provided a heated filament 16 which serves as a source of electrons. The temperature of the heated filament and thus the number of electrons which are emitted therefrom are controlled by a voltage controlled heater supply source 18. This may constitute any of the well-known voltage controlled power supplies wherein the current output may be determined by a voltage applied to the regulating tube or transistor therein. The electrons which are emitted from the filament 16 can pass through a grid 20 only when the potential of this grid is raised above the cutoff bias level. This can only occur when a pulse is applied to the grid 20 from a pulse generator 22. The emitted electrons can pass through the grid 20 into a shielded region 23 into which there is admitted gas from the source 14. At the side of the shielded region, which is opposite to the electron input side, there is positioned a collecting anode 24. This collecting anode is biased positively to attract thereto electrons which have passed through the shielded region. This collecting anode is also shaped to eliminate or prevent soft X-rays produced by electron impact from reaching an electron multiplier 32.

The pulse generator 22 applies a pulse to the grid 20 whereby electrons are permitted into the shielded region 23. There they collide with any molecules in the gas admitted from the source 14. Thus, they provide ions of the gas. The output pulse from the generator 22 is also applied to an acceleration grid 26 which forms a wall of the shielded region 23, nearest the outside of the tube 10. This is a positive pulse which is applied through a delay circuit 30 which delays the application of this pulse to the acceleration grid for the time required by the pulse applied to the control grid 20 to subside. The acceleration grid 26, when it is pulsed, accelerates any ions which are created into the drift region of the tube 10. These ions travel down the tube toward the opposite end wherein an electron multiplier 32 is placed. Before an ion hits the electron multiplier 32, it is given a boost in energy by acceleration to the first dynode of the electron multiplier tube by the effect of the 3 kilovolts bias voltage applied to the first dynode 34 of the tube 32.

To accurately determine the mass number of an ion, it is important that no stray fields impart a velocity to the ion before or during its flight period. The field set up by the control grid 20 and the anode 24 are isolated from the long flight path of the ion by a uniform field grid 36. The uniform field grid 36 is connected to an electrically conducting center portion 38 of the tube 10, so that the center volume of the tube is almost equipotential and there is little field to accelerate an ion during the center periods of its flight.

When the ion hits the electron multiplier 32, the multiplier generates a current pulse which it feeds to a low jitter discriminator and pulse forming circuit. This circuit provides a pulse output to a gate circuit 42. An oscillator 44, which is continuously oscillating, applies its output to the gate circuit. The gate circuit however does not pass the output of the oscillator to the following circuitry, consisting of a scaler circuit 46, unless the gate circuit has received the "start" pulse from the pulse former 40. The gate 42 remains open in response to the pulse generated by a received ion until it is closed by a pulse received from the pulse generator 22. This is applied to the gate through a delay circuit 48, which delays this pulse for a predetermined time interval after the application of the accelerating pulse.

The output of the gate circuit 42 is applied to a scaler 46 which indicates by the number of oscillations counted, the time of flight of the ion. Since the occurrence of the turn-off pulse is fixed, the greater the number of oscillations which are counted, the shorter the time of flight of the ion and the shorter the number of oscillations which are counted, the greater the time of flight of the ion. The scaler output is recorded by any suitable memory device 50.

Since the apparatus described and shown is to measure the time of flight of one ion, it is important that only one ion be created and accelerated at a time. Otherwise, the fastest ion would turn on the oscillator while the slower ions would have no effect and the instrument would show a higher proportion of faster (lower mass) ions. To prevent this, the number of electrons made available for the purpose of ionization is adjusted so that, on the average, only one ion is created for every five ionizing pulses from the pulse source 22. As a result, two ions are seldom created at the same time.

In order to effectuate the above-described operation, the current pulse provided by the receipt of an ion on the electron multiplier tube 32 is applied to a count rate meter 52. The count rate meter is a commercially purchasable item of electronic equipment which counts pulses over a predetermined interval from the output of the pulse former 40 and provides an output voltage indicative of the average count which it attains. This voltage is applied to a comparator 54 which compares it with the voltage from a constant voltage source 56. The difference, or error signal, is applied to the voltage controlled heater supply source 18. It will be appreciated that by setting the value of the reference voltage source 56, one can determine how much current is applied to the filament 16 from the supply source 18 and thereby can determine how many electrons are available for creating ions. This voltage setting is established to provide only enough electrons so that on the average, only one ion is created for every five ionizing pulses.

Though the embodiment of the invention shown uses a grid control stream of electrons to ionize gas for acceleration, any other suitable controllable ionization means, such as radioactive source with a shutter or light beam impinging on an electron emissive surface to produce ionizing electrons, can be used. Since the oscillator is only turned on in the presence of an ion to be counted, no useless operation of the circuit occurs.

While a specific embodiment of the invention has been selected for detailed description, the invention is not, of course, limited in its application to the embodiment described. The embodiment which has been described should be taken as illustrative rather than restrictive. The individual circuits represented by rectangles in the drawings are well known in the field and both their operation and interconnections are easily performed by those skilled in the art. Therefore a detailed description of these circuits is omitted.

What is claimed is:

1. A time-of-flight mass spectrometer comprising a tube having at one end means for generating at predetermined intervals ions whose time of flight are to be measured, means for accelerating said ions through said tube to the other end, means at said other end for generating a voltage pulse responsive to the receipt of an ion, oscillator means, counter means, gate means rendered operative responsive to said voltage pulse for applying oscillations from said oscillator means to said counter means to be counted, and means for rendering said gate means inoperative at a predetermined time after an operation of said means for generating ions for preventing further application of oscillations to said counter means whereby the

time of flight of said ions is inversely proportional to the count of said counter means.

2. A time-of-flight mass spectrometer as recited in claim 1 wherein said means for generating at predetermined intervals, ions whose time of flight is to be measured, include:

means for admitting external gases to said one end of said tube;

a pulse generator;

means for ionizing molecules of said admitted external gas responsive to a pulse from said pulse generator;

said means at said other end of said tube for generating a voltage pulse responsive to the receipt of an ion includes electron multiplier means for generating an output signal responsive to receiving an ion.

3. Apparatus as recited in claim 2 wherein there is additionally included:

means responsive to the output signals generated by said electron multiplier means for generating a control voltage representative of the number of output signals produced by said electron multiplier means over a predetermined interval of time; and

means responsive to said control voltage for controlling the number of ions produced by said means for ionizing the molecules of said external gas.

4. Apparatus as recited in claim 1 wherein the center region of said tube through which said ions are accelerated contains:

means for substantially isolating said region from stray field including:

a conductive inner lining for said region; and

a perforate grid at the end of said conductive inner lining nearest the end of said tube containing said means for generating a voltage pulse responsive to the receipt of an ion.

5. A time-of-flight mass spectrometer comprising an elongated vessel having an opening at one end for admitting gas desired to be ionized, an enclosure adjacent said opening to receive gas therefrom, an accelerating grid constituting a first wall of said enclosure which is positioned opposite the opening for admitting gas to be ionized, a second wall of said enclosure adjacent said accelerating grid having an electron exit opening, an anode electrode positioned adjacent said electron exit opening outside of said enclosure, a third wall of said enclosure opposite said second wall having an electron entry opening therein, a control grid positioned outside of said electron entry opening, a cathode structure adjacent said control grid, a controllable current source connected to said cathode structure, pulse generating means connected to said control grid for enabling said control grid to pass electrons from said cathode structure in response to a pulse from said pulse generating means, delay means connected between said pulse generating means and said accelerating grid for applying a pulse to said accelerating grid at a predetermined interval after the application of a pulse to said control grid, electron multiplier means positioned at the end of said elongated vessel opposite said one end for generating a signal voltage responsive to an ion being received thereby, means for producing oscillations, gate means to which said oscillations are applied, said gate means being rendered operative responsive to said signal voltage, means for applying a pulse from said pulse generator means at a predetermined interval after the application of a pulse to said accelerating grid to said gate means to render it inoperative, means for counting the number of oscillations in the output of said gate means over the interval during which it is operative to provide an indication representative of the ion time of flight, and means responsive to the number of signal voltages occurring over a predetermined interval of time for controlling the controllable means for applying current to said cathode structure so that a predetermined number of ions is produced for a predetermined number of pulse outputs from said pulse generating means.

6. A time-of-flight mass spectrometer as recited in claim 5 wherein said means responsive to the number of signal voltages occurring over a predetermined interval of time for controlling said controllable means for applying a current to said cathode structure comprises means for establishing a voltage representative of the number of signal voltages occurring of time, a reference voltage, means for comparing said generated voltages with said reference voltage to product an error signal, and means for applying said error signal to said controllable means for applying a current to said cathode structure.

7. A time-of-flight mass spectrometer as recited in claim 5 wherein said elongated vessel has a center region between said one end and the end opposite said one end comprising a flight region, said flight region containing means for substantially isolating said region from stray fields including a conductive inner lining for said region, and a perforate grid at the end of said conductive inner lining nearest the end of said enclosure containing said electron multiplier means.

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