A New Twin Ion Source Mass Spectrometer

—Design Consideration—

ISAO NISHI*

(Received 8 March 1976)

A new type twin ion source mass spectrometer is being developed with intending to make a simultaneous and continuous measurement of two samples of low mass. The most interesting application will be found in the simultaneous measurement of the respiratory gas and the blood gas. The principal construction of the instrument is a voltage scanning sector type mass spectrometer with two direct gas introduction system (the response of which is higher than 50 ms in the rise time of 95%) connected to the twin ion sources. The sources are made from one block and the arrangement of which is of side by side for the easiness of construction. The magnetic field of 180 degree type is modified as to make the two source points and their image lines located just outside the magnet boundary with retaining the two image lines almost superposed and parallel to the boundary.

The spacing between the twin sources is determined as well as the positions of the two collectors so that the ions of the same mass from two sources are simultaneously accepted by the respective collectors and the beams should not be interfered by other ions from the neighbouring sources at their collector position for all the ions of interest in the respiratory applications.

Ions to be detected are selectively scanned by the step-wise potential with the frequency of about 100 Hz. After amplified, the ion peaks are separated to the respective channels through analogue switches which are operated associating with the corresponding steps of the scanning potential.

The mixing rate of the two samples between the twin sources should be determined so as to take a counterbalance with the clearance response of the ion source: the rate is obtainable as low as 1/200 without any compensation, with retaining the response of 50 ms in the rise time of 95%.

In this paper, the description of the instrument designed will be presented with some discussions on several peculiar technical problems.

1. Introduction

A new parallel type twin ion source mass spectrometer is being developed for the simultaneous and continuous gas analysis of low mass. The twin ion source is named here for the two ion sources of similar properties. The twin ion source mass spectrometer may be used not only to make a simultaneous measurement of samples from two different points, but also to make the precision improved in the measurement of mass and intensity by comparing the sample with the standard which is introduced into one of the twin. On the design of the twin ion source mass spectrometer, the following requirements are first to be taken into consideration.

(1) Avoiding the superposition of the two beams at the collector position.

(2) Avoiding or minimizing the scattering of the ions caused by crossing of the beams in their flight.

(3) Minimization of the mixing of the samples between the twin sources.

(4) Symmetrical construction of the two sources.

Two different types of the twin source have

* Science Univ. of Tokyo (2641, Higashi-Kameyama, Yamazaki, Noda-shi, 278 Japan)
been considered according to their arrangements, as illustrated in Fig. 1 and Fig. 2. In the former, the two beams are collimated not be crossed in their whole path. This type is more advantageous in the symmetry, while it needs wider magnetic pole gap. The double focussing mass spectrometer of this type has been already manufactured by M. Barber et al. One of the twin sources is used as the mass marker-making. In the latter case, the twin sources are arranged side by side, we call “the parallel type” for such a arrangement. The application of this type has been limited up to now only to the isotope separation of some kind due to the cross of the beams. For general use, some contrivance is needed to avoid such a crossing of the beams, at least at the image points, while this type may be more advantageous in the construction for its easiness of arrangement, especially for the case of single focussing. We are now intending to develope the wider application of this parallel type twin ion source mass spectrometer by cultivating some technical contrivance to meet the requirements previously listed. The most interesting application will be found in the study of respiratory and circulatory systems.

In this paper, the general layout of the parallel type twin ion source mass spectrometer which has been designed is presented. Some technical points are examined and discussed with the intention of applying it to the simultaneous analysis of the respiratory and blood gases.

2. Description

The system is composed of the twin ion sources of parallel arrangement, the magnetic analyser of 180° deflection, the multi-collector assembly, two lines of direct gas introduction system and the controlling and measuring system involving the multi-peak selection circuit. The ions from the twin sources are accelerated by the selective step-wise scanning voltage and, in ordinary use, accepted by two collectors. After amplified, the ion peaks are led to the analogue switches (gate assembly) which conduct the peaks to the respective channels by the gate pulses accompanied with the corresponding steps of the scanning voltage. After separated the intermittent ion peaks are smoothened through the active filters with retaining the necessary response to follow the changing concentration of the sample.

Crossing of the beam at the image points can be avoided by placing the twin sources on the appropriately selected positions for an given electro-magnetic field. In the present case, two collectors are provided with the spacing of same as between sources as to make a simultaneous measurement of two samples of same mass from the twin sources with applying a potential or a magnetic scanning. The ratio of the spacing over the radius of the ion trajectory is taken 10/56 as a optimum condition for the respiratory use. The radius is taken 56 mm and the spacings 10 mm. The ratio can be varied by moving the collectors on the scaled rod along the focal line.
to obtain a optimum setting positions for other applications. The multi-collector assembly is also available to make a simultaneous measurement with employing a fixed accelerating and deflecting field. The situation is illustrated in Fig. 4. Such contrivances may be restricted only to the case of selected mass measurement, our interest is now in the respiratory gas analysis. The scattering of the ions in their flight is negligible at least in the respiratory applications. For general applications, the alternative cutting, which allows two beams alternatively to enter the analysing...
region through the defining slits, should be employed. This operation can be performed by using two deflectors D₁ and D₂.

As is seen in Fig. 4, the shape of the magnet is somewhat modified from the usual type of 180 degree so as to locate both the source points and the focal points just outside the boundary of the magnet remaining them on the parallel lines to the boundary.

The peak selection circuit to be employed is that already developed for the respiratory mass spectrometer. The central part of the circuit is composed of (1) a step-wise scanning voltage supply, (2) the gate circuits, (3) a timing circuit which controls the gates together with the corresponding steps of the scanning voltage. The timing circuit is composed of a basic square wave generator, a sixth-fold ring counter and a assembly of logic elements. The performance of the measuring circuit is presented in Fig. 5 by illustrating the peaks of Nitrogen, Oxygen and Argon in air before and Nitrogen after passing the gates together with the step-wise selective scanning voltage and the gate pulse which is provided synchronizingly with the corresponding step. The smoothed output is illustrated with the original intermittent ion peaks in Fig. 6. The stability of the peak selection circuit is proved to be almost perfect for the respiratory applications. This may be attributed to the larger tolerance of construction for the respiratory use.

The interference of the twin source is estimated to be as low as one part over 200 without any compensation with retaining the sufficient clearance response of 50 ms.

3. Discussion

Let's have some examinations and discussions on the technical key points peculiar to the twin ion source mass spectrometer with the special intention of applying it to the respiratory use.

3.1 Superposition of two beams at the collector position

In the respiratory applications 45 (¹³CO⁺), 44(CO₂⁺, N₂O⁺), 40 (A⁺), 32 (O₂⁺), 30 (NO⁺, C⁸O⁺), 28 (N⁺), 26 (C₃H⁷⁺), 22 (CO₃⁺), 21 (Ne⁺), 20 (A⁺⁺), 19 (F⁻ from SF₆), 17 (OH⁻ from H₂O), 16 (O⁺⁺ and O⁺), 14 (N⁺⁺ and N⁺), 12 (C⁺ from CO₂ and vacuum oil vapour) and 4 (He⁺) in atomic mass unit are the mass over valences (M/Z) of interest. Carbon di-Oxide (CO₂), Argon (A), Oxygen (O₂), Nitrogen (N₂) and
A New Twin Ion Source Mass Specmeter

Water vapour (H₂O) are common components of the respiratory gas. For some advanced tests and inspections on the functions of the lung and the circulatory system, it may be beneficial to use simultaneously two or three more gases which have different properties in physical, chemical and physiological sense: SF₆, A, N₂, Ne and He are more useful to study the ventilation of gases in the lung, N₂O, C₂H₂ perfusion of blood and cardiac output, C¹⁸O diffusion of gases through the alveolar membrane. The simultaneous measurement of the respiratory gas would surely make the information more accurate and detail.

As seen in Fig. 4, the image line of the ions from source 1 is just a replica of that from another and is obtained by being parallely moved by the spacing of two source points. The spacing between the twin sources can be determined so that the ions from two sources do not superpose each other at their image points for an applied accelerating and magnetic deflecting field. The situation is illustrated in Fig. 4. The minisize multi-collector assembly is available to accept those selected ions, the collectors here are movable and adjustable on their scaled supporting rod.

With varying applied field, the mutual focusing situation is altered. Let's examine the superposition provided with a single collector system first, next with the dual collector assembly. The dual collector assembly with the spacing of same as that between sources are going to be adapted for normal use in the present case, so that it allows to accept simultaneously the ions of same mass which emerge from the twin sources. Considering that the ions from source 1 and 2 are simultaneously falling to a single collector as is seen in Fig. 7, we have the following relation

\[
\frac{M}{M_0} = \left(1 - \frac{X}{2R}\right)^2
\]

where \(M_0\) and \(M\) represent the mass per valences in a.m.u. from source 1 and 2 respectively, \(R\) is the radius of the trajectory of the beam from source 1 and \(X\) is the difference of the radius of another beam from that of former. Here, \(x = d_i\), \(d_i\) is the spacing of the twin sources. The graphic representation is shown in Fig. 8 in the region of \(|X/R| < 0.25\); the larger \(X/R\) may be impractical. We can tell you the forbidden values of \(d_i/R\) for the components of interest from this graph. Positive or negative region of \(X/R\) represents that the beam of interest is emerging from the left hand side source or the right hand side source. For the practical applications, some width should be considered on the graphical line. The width may be roughly estimated as \((S_e + W)/R (\approx 1/(Resolving Power))\), where \(S_e\) and \(W\) are the width of the collector slit and the width of the beam at the slit. For the dual collector assembly as illustrated in Fig. 9, the consulting should be also performed for the added collector with the same graph by replacing \(R\) to \(R' (=R + dc/2)\), where \(dc\) is the spacing between the two collectors, it is taken positive to the right direction as is the case of \(d_i\). The forbidden values of \(X/R\) are...
Fig. 8. Graphic representation of $M/M_0 = (1 - X/R)^2$ in the region of $|X/R| < 0.25$: practical condition of two beams. Positive or negative sign of $X/R$ tells us that the beam of interest is emerging from the left hand side source or from the right hand side source. Some width should be considered on the graphical line. The width may be roughly estimated as $(S_c + W)/R$, where $S_c$ and $W$ are the width of the collector slit and the beam at the slit. The dashed lines emerging from the points $X/R = \pm 0.1/6$ tell us that the beam of C$_x$H$_y$ (mass 26) from source 1 is interfered by the beam of CO$^{+2}$ (22) from source 2 at the collector C, in Fig. 10, provided with $R = 60$ mm, $d_i = d_c = 10$ mm, and $S_c + W = 1.1$ mm. All the interference to be considered may be avoided in the respiratory applications only by reducing $R$ to 56 mm with remaining $d_i = 10$ mm.

Tabled with the corresponding $M/M_0$ for the respiratory gas components in Table 1. The optimum $d_i/R$ and $d_c$ should be determined by consulting with that graph or this table and by considering together some other technical requirements. For our present arrangement as is illustrated in Fig. 10, where $d_c = d_i$ and the beams of same mass from the twin sources $S_1$ and $S_2$ are simultaneously accepted by the re-
Table 1. All the forbidden $X/R$ s (upper) are tabulated together with related $M/M_0$ s (lower) of interest in the respiratory uses according to $M/M_0=(1-X/2R)^2$. The positive values of $X/R$ represent the interference from the right side source to the left side source and vice versa. The numbers which should be especially scanned are underlined. $d/dR=10/56$ is the optimum for the universal respiratory applications, while 10/58 may be preferable for most of the respiratory applications, where Ne and SF$_6$ are scarcely used, and C$_2$H$_2$ can be replaced by N$_2$O, because this value gives larger tolerance for construction.

<table>
<thead>
<tr>
<th>$M$</th>
<th>$M_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1.000</td>
</tr>
<tr>
<td>12</td>
<td>3.000</td>
</tr>
<tr>
<td>14</td>
<td>3.500</td>
</tr>
<tr>
<td>16</td>
<td>4.000</td>
</tr>
<tr>
<td>18</td>
<td>4.250</td>
</tr>
<tr>
<td>20</td>
<td>4.750</td>
</tr>
<tr>
<td>22</td>
<td>5.000</td>
</tr>
<tr>
<td>26</td>
<td>6.500</td>
</tr>
<tr>
<td>28</td>
<td>7.000</td>
</tr>
<tr>
<td>30</td>
<td>7.500</td>
</tr>
<tr>
<td>32</td>
<td>8.000</td>
</tr>
<tr>
<td>40</td>
<td>10.000</td>
</tr>
<tr>
<td>44</td>
<td>10.000</td>
</tr>
</tbody>
</table>

A New Finn Source Mass Spectrometer
spective collectors $C_1$ and $C_2$, the examination should be performed simultaneously with $X = \pm d_i (= d_c)$. We obtained $10/56$ as the optimum value of $d_i/R$ for the respiratory uses by taking $R = 56$ mm, $d_i = 10$ mm. In this arrangement, no interference may be occurred on the ions of interest provided with $(S_c + W) = 1.1$ mm. For the usual respiratory applications, however, it may be preferable to choose $d_i/R = 10/58$ for its larger tolerance of $(W + S_c)/R$ because $C_i H_2$, Ne and SF$_6$ are not frequently used.

It should be noted that the essential numerical difference is not found between 180 degree deflection type and our modified type.

3.2 Mixing of the sample between the twin sources

Let’s consider the mixing rate of the sample on the arrangement of Fig. 11. Now let $Q_{i1}$ and $Q_{i2}$ the flow quantities of component $i$ flowing into the source 1 and 2, and $C_i$ and $C_2$ the conductances of the exits of the source 1 and 2 respectively and $S$ the pumping speed of the outside of the sources. The increment of the partial pressure caused by $Q_{i1}$ is estimated $\frac{C_i}{S} \left( \frac{1}{1 + C_i/S} \right)$ in the source 1 and $\frac{C_i}{S} \left( \frac{1}{1 + C_i/S} \right)$ in the instrumental chamber and in the source 2 when the equilibrium is attained between inside the source and outside the source. Then we have the mixing rates in the source 1 and 2 as $\frac{C_i}{S} \left( \frac{1}{1 + C_i/S} \right)$ and $\frac{C_i}{S} \left( \frac{1}{1 + C_i/S} \right)$ respectively. For the exact symmetrical construction where $C_1 = C_2 = C$, we get

$$\frac{C}{S} \left( \frac{1}{1 + C/S} \right) \approx \frac{C}{S}$$

The smaller $C$ and the larger $S$ are preferable to make a mixing rate smaller. On the other hand, we need larger $C$ to make a clearance time smaller because the clearance is characterized by $\exp(-V_i/C)t$, where $V_i$ is the equivalent space of an ion source. In the present case, we have $C \approx 0.4 \ l/s$, $S \approx 100 \ l/s$ and $V_i \approx 40 \ cm^3$ intending to make the mixing rate smaller than $1/200$ and the clearance time of $98\%$ smaller.
A New Twin Ion Source Mass Spectrometer

than 50 ms to follow any change of respiratory
gas sample with a sufficient response and accu-
ry. The electronic compensation would be
performed only when much smaller mixing rate
is requested. The compensation is performed
only by inverting a certain fraction of one output
and adding it to another. When the rapid
changing concentration is concerned, the delay
of the interference should be taken into con-
sideration. The response may be simulated
through a simple CR circuit for the symmetrical
properties of the relaxation of the gas concen-
tration to that of the electric charge through CR
circuit.

3.3 Symmetrical construction of the twin
source

The symmetry of the twin sources are
attributed not only to the properties of the ion
source, the ion optics and the pumping lines
but also to the gas inlet process. Much care is
taken to the temperature control of the twin
sources as well as to the symmetrical construc-
tion of two sources and two lines of gas intro-
duction. The symmetry however is also affected
by the properties of the sample itself. Many
problems will be remained undetermined especial-
ly on this point until they will be examined in
the practical applications.

Acknowledgement

The author express his thanks to Mr. S.
Sugai and Mr. Y. Tabata for their assistances
in calculation and useful discussions. The
author also express his sincere gratitude to Dr.
K. Kawasaki, Dr. H. Hasunuma, Profs. of
Physics of Science Univ. of Tokyo for their
constant encouragements on this work.

References

1) M. Barber, J. R. Chapman, B. N. Green and T. O. Merren,
2) B. Dunjic, Nuclear Instruments and Methods, 40, 309-317
(1966).
4) I. Nishi, S. Sugai, K. Tanaka, To be published in Mass
Spectroscopy Japan.