The History of Magnetic Sector Mass Spectrometry at VG - Micromass - Waters

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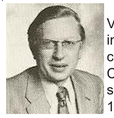
EARLY DAYS

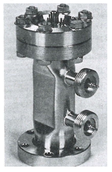
The commercial history of mass spectrometry in Manchester, England, dates back to the 1940s with the development of a mass spectrometer by Metropolitan Vickers for the separation of Uranium isotopes (MS1) for James Chadwick at the University of Liverpool. Metropolitan Vickers became AEI (Associated Electrical Industries).



Robert Craig

Vacuum Generators was a company based in the south of England manufacturing components for vacuum systems. Robert Craig was instrumental in the magnetic sector business at AEI. He joined VG in 1968, and VG Micromass was formed in 1970.

The first instrument manufactured by VG Micromass was the MM1 1cm radius 180° magnetic sector instrument for residual gas analysis. This was followed by the 6cm radius single focusing MM6 in 1970 and the 12cm radius MM12 in 1971. In parallel with this, quadrupole mass filters were also introduced, with the Q7 (m/z range 120) and the Q8 (m/z range 300).



VG Micromass MM-1

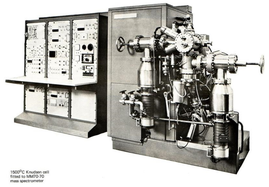
VG Micromass MM-12

The timeline for the evolution of the company is shown in the Table below, culminating with the full integration of the VG/ Micromass businesses with Waters in 2002.

1962	VG Instruments Group formed (Vacuum Generators Ltd)
1970	VG Micromass formed to specialize in MS
1974	VG Organic formed to specialize in Organic MS
1980	VG Analytical Formed
< 1985	VG products distributed in the US by the Kearns Group
1985	VG Instruments buys out Kearns Group
1990	VG Instruments Group purchased by Fisons Instruments
1991	VG Biotech Formed
Jan-95	Fisons announces sale of Fisons Instruments to Thermo Instruments
Mar-95	SEC investigates MS monopoly possibility resulting from Fisons acquisition by Thermo
Mar-96	Micromass Ltd. formed from VG Analytical, Biotech
Mar-96	Micromass Management Buyout Completed
Sep-97	Waters buys Micromass
Jun-02	Full Integration of Micromass with Waters

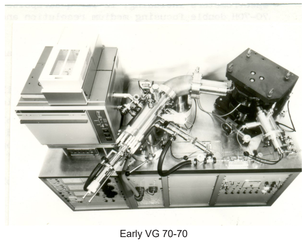
70-70

In 1974, VG Organic was formed to specialise in organic mass spectrometry. The first double-focusing mass spectrometer constructed by VG was the 7.5" radius, 70° electric sector followed by a 5" radius 70° magnetic sector, and known as the MM 70-70. The first instrument was made for Sheffield University, and was constructed in a vertical geometry - the only VG double-focusing instrument to be built in this orientation.



VG 70-70 with Knudsen cell

Subsequent iterations of the 70-70 were engineered in the horizontal plane, and changes were made in the vacuum pumping to accommodate chemical ionisation. The first of these was delivered to the Department of Pharmacology at Oxford University in 1975, and presented to the Museum of Science and Industry in Manchester, England when it was decommissioned in 1995.



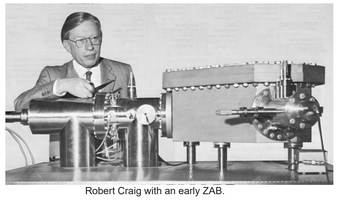
Early VG 70-70

One of the major breakthroughs in magnetic technology was introduced in 1980 with the laminated magnet that minimised stray fields, reduced the hysteresis of the magnet, and essentially eliminated eddy currents which permitted fast scanning. This was particularly pertinent in the environmental analysis field for the quantification of dioxins.

VG 70-70E with extended mass range

ZAB

Work started on the Hintenberger and König reverse geometry ZAB to meet the requirements of John Beynon (Swansea, Wales) to allow the performance of Mass-Analysed Ion Kinetic Energy (MIKES) spectrometry, and acquire CID-MIKES spectra. The ZAB included an 11.75" radius 55° magnetic sector followed by a 15" radius 81° electric sector and had zero first and second order alpha (angular divergence) and beta (energy divergence) aberrations.



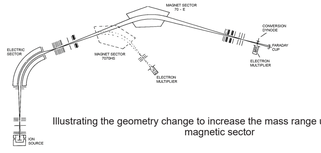
Robert Craig with an early ZAB.

The 'reverse' (BE) geometry of the ZAB instrument was configured with a detector after the magnet as well as after the electric sector, and allowed it to be operated as both a single– and double-focusing instrument. This configuration also allowed for mass selection after the magnet to allow for MS/MS experiments to be undertaken.

HIGH MASS

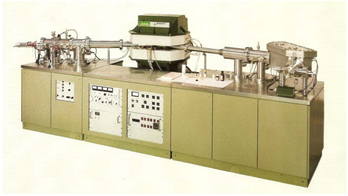
The advent of commercial fast-atom bombardment (FAB) in the early 1980s was a stimulus in the development of high-mass sector instruments, as it allowed the study of biomolecules directly, which were previously intractable by mass spectrometry. The mass range of a magnetic sector is proportional to the square of the magnetic field radius but, as the radius of the magnet is increased, the whole instrument must be scaled up in order to maintain the double focusing criteria., thus increasing the physical size (and cost) of the instruments. The challenge was to develop an instrument that had a high mass range, but maintained sensitivity and mass resolution without being too large and expensive.

VG addressed this issue by rotating the entry and exit angles of the ion beam into the magnetic field and repositioning the magnet. This approach was first introduced in the VG 70-E instrument, and effectively quadrupled the mass range of the mass spectrometer.



Illustrating the geometry change to increase the mass range using the same magnetic sector

The same principle of rotating the magnet pole faces to extend the mass range was also applied to the ZAB series of instruments, with the ZAB-SE including a 26" radius high-field magnet delivering a m/z range of 15,000 at 8kV accelerating potential.



The extended geometry ZAB-SE

AUTOSPEC

1988 saw the introduction of the tri-sector Autospec at the IMSC Conference in Bordeaux France. This sector instrument, of geometry EBE, used the energy and angular focusing properties of the three sectors to fulfil the double-focusing requirements of the ion beam at the detector, while still having the advantages of both the 70 series (forward geometry, EB) and ZAB series (reverse geometry, BE) instruments.

VG Autospec

A special version of the Autospec was made in 1989 for CDC in Atlanta, GA with a wider magnet gap, which improved transmission and stability at a reduced mass range. However, the mass range was still adequate to be used for the GC/MS analysis of environmentally hazardous compounds (e.g. dioxins and polychlorinated bipehnyls).

The Autospec series was also offered in tandem configurations, with the Autospec 6F offering the ultimate tandem sector geometry.

VG Autospec –6F tandem mass spectrometer

The last sector instrument from the VG-Micromass-Waters stable - Autospec #889 - was shipped from the Wilmslow facility in the UK in December 2016.

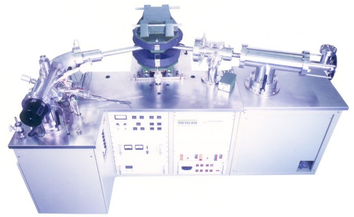
Final test for the last Autospec with Brian Green, Martin Elliott, Tom Merren and Bob Bateman

MS/MS

The soft ionisation characteristic of FAB, which led to its success in the analysis of large biomolecules, also meant it produced little fragmentation and little structural information. This prompted the development of commercial tandem mass spectrometers with the production of a four-sector ZAB-HF instrument of BEEB geometry (1984), with a collision cell positioned between the two electric sectors. The extended geometry ZAB-SE BEEB four-sector was produced in 1986, with a floor space requirement of 9m x 3.5m.

VG ZAB four sector tandem mass spectrometer

VG Analytical also introduced the first commercial magnetic sector-quadrupole hybrid MS/MS instrument, the VG 70-EQ that consisted of a VG-70E for precursor ion selection, an RF-only quadrupole gas collision cell, and a modified 12-12 quadrupole that allowed for the operation of the quadrupole at 6kV above ground.



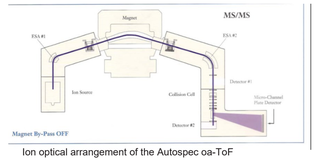
VG 70-SEQ tandem mass spectrometer

In 1990, an array detector was introduced as the final detector in a multi-sector tandem instrument, the ZAB-T with a novel focal-plane geometry as the second analyser. These devices were particularly suited to the collection of product ion mass spectra with minimal chemical noise. The instruments themselves, however, were substantial pieces of hardware.

VG ZAB-T with array detector

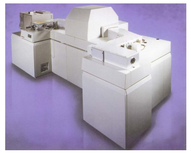
OA-TOF

In 1989, Jim Dawson and Mike Guilhaus of the University of New South Wales, Sydney, published a paper on an orthogonal acceleration time-of-flight analyser, and it was presented at ASMS in 1992. Guilhaus visited VG Analytical on his journey back to Australia to discuss implementation. At VG, the oa-ToF was seen as a potential second analyser in a tandem instrument as a simpler and smaller configuration than the tandem sector constructs of the Autospec-T.



Ion optical arrangement of the Autospec oa-ToF

The implementation of the oa-ToF led to a number of instrumental developments, including the Autospec oa-ToF.



Autospec oa-ToF

Deeper understanding of the capabilities of the oa-ToF technology led to a significant number of instrument developments in the VG-Micromass-Waters evolution, which will be covered in a separate article.

REFERENCE: R H Bateman in K R Jennigs (Ed.) A History of European Mass Spectrometry, IM Publications, (2012).