

Atmospheric Pressure Ionization Permanent Magnet FTICR Mass Spectrometer: A Way to High Performance Mass Spectrometry in a Bench-Top Size

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INTRODUCTION

Development of a hybrid permanent magnet based Fourier Transform Ion Cyclotron Resonance (FTICR) mass spectrometer with atmospheric pressure ionization (API) sources results in a new class of MS instruments that combine the unique features of FTICR mass spectrometry such as high resolution and mass accuracy and a cost efficiency of bench-top low-end MS systems. In this work we report on the first results of our continuous efforts on development of a hybrid bench-top FTICR mass spectrometer and discuss its basic features and principal limitations.

INSTRUMENTATION

Permanent magnet

The developed mass spectrometer is based on a hybrid LIT-FTICR approach in which a permanent magnet is used instead of superconductive magnet utilized in commercial FTICR-MS. In this work we report on the results of our evaluation for a novel yokeless permanent magnet based on the reversible magnetic field (RMF) approach [M.V. Gorshkov, US Patent Appl. Ser. No. 11/130,138, 2005]. The magnet has a bore diameter of 42 mm and weight of 37 kg. The accurate magnetic field profiling has demonstrated the field strength of 0.97 Tesla (along the central axis of a magnet bore) and the field homogeneity of 500 ppm (over a central 1 cm³ volume of the magnet).

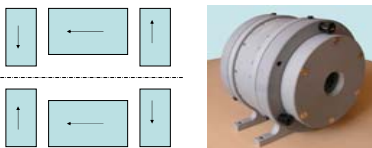


Figure 1. Novel yokeless permanent magnet based on the reversible magnetic field (0.97T).

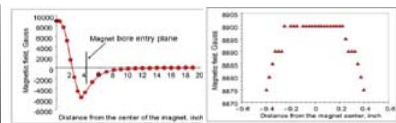


Figure 2. The homogeneity of the magnetic field in the central 1 cm³ volume of the permanent magnet bore along the radial (a) and axial (b) directions.

To optimize field homogeneity, a room temperature coil shimming has been implemented inside the permanent magnet. By changing the amplitude and direction of a current passing through shimming coils, magnetic field homogeneity below 50 ppm has been achieved with total power consumption less than 0.5W.

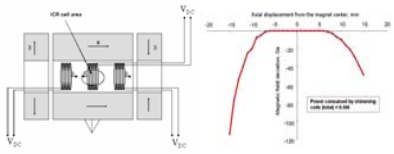


Figure 3. Axial magnetic field profile (right) near the center of the permanent magnet with shimming coils (shown on the left side).

Vacuum system

The instrument developed consists of three major parts: an electrospray atmospheric pressure ionization (ESI) source, an RF multipole-based ion accumulation and transportation system, and 0.97T permanent magnet FTICR mass analyzer. A permanent magnet has 42 mm bore and generates an axial, solenoid-type magnetic field with homogeneity below 50 ppm over a central 1 cm³ region. A compact vacuum system has 5 stages of differential pumping with full length less than 1 m. An RF ion guide provides ion transportation through differential pumping stages from ESI source to ICR cell. One of the RF quadrupoles is segmented and works as a linear ion trap (LIT) for ion accumulation, selection and collision-induced fragmentation.

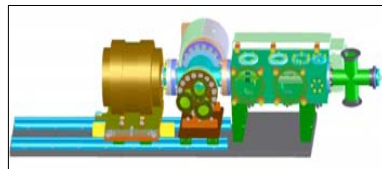


Figure 4. 0.97T permanent magnet FTICR instrument with atmospheric pressure ionization source: SolidWorks model (top) and photo of the built instrument (bottom).

Data Station Architecture

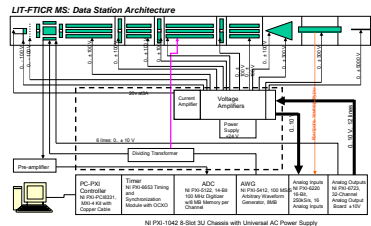


Figure 5. Schematic diagram of FTICR data station architecture. Data control system is based on PXI cards from National Instrument. All DC voltages are supplied using a home-built Voltage Distribution unit consisting of 12 voltage amplifiers (providing up to 300 V), a current amplifier for e-gun, and incorporates UHV power supply from Applied Kilovolts for ESI, dividing transformers for excitation of cyclotron motion and ions isolation and fragmentation in a Linear Ion Trap. The outputs from amplifiers are measured for system control and parameters optimization purposes.

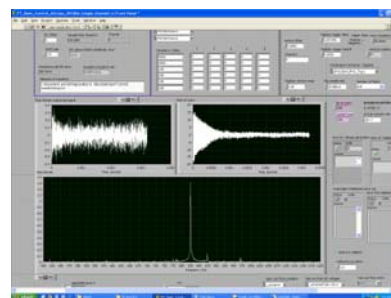


Figure 6. LabView-based GUI data acquisition interface.

PRELIMINARY RESULTS

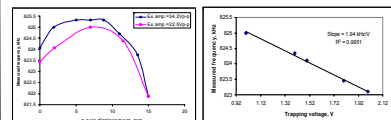


Figure 7. Dependence of the measured effective frequency ($\nu_e - \nu_m$) on the ICR trap position relative to the magnet at different post-excitation radii (left). Drop in measured frequency at lower radius is attributed to space charge effect. The magnetron shift in measured frequency ν_m has been determined by changing the voltage on trapping electrodes of the cell (shown on the right side). The magnetron frequency was measured to be 1.9 kHz/1V_e which is in good agreement with predicted.

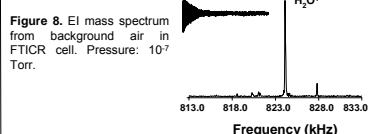


Figure 8. EI mass spectrum from background air in FTICR cell. Pressure: 10⁻⁷ Torr.

CONCLUSIONS

- ✓ Novel 0.97 Tesla yokeless permanent magnet based on the reversible magnetic field (RMF) approach has been developed and manufactured. The measurements show ~500 ppm homogeneity over 1 DS. The additional shimming coils allow to improve magnetic field homogeneity up to 50 ppm.
- ✓ RMF approach allows to built permanent magnets with axial magnetic field suitable for FTICR instruments with atmospheric pressure ionizations sources. A new magnet with 1.23 Tesla axial magnetic field and 5 cm bore has been built and tested (shown in Figure 9).
- ✓ A prototype hybrid LIT-FTICR mass spectrometer with multi stage differential pumping vacuum system and electrospray ion source has been developed and manufactured. The system is currently under evaluation at MasTech, Inc.



Figure 9. 2.1 T permanent with 5 cm bore and 75 kg weight. Field homogeneity (no shimming) is 500 ppm.

ACKNOWLEDGEMENTS

Authors thank SBIR/NIH program (grant 1 R43 GM68393-01), INTAS (grants 04-83-2643 and Genomics-05-1000004-7759), Russian Foundation of Basic Research (grant 06-04-49632), and Civilian Research and Development Foundation (grant RUE1-000588-MO-05) for partial support of this work. Also, authors thank Kevin Felber for mechanical design of the vacuum system.

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