Test operation of a novel Time-Of-Flight mass spectrometer on the gas exhaust of Wendelstein 7-X

G. Schlisio,[1,*] S. Gasc,[2] L. Hofer,[2] C.C. Klepper,[3] and the W7-X team[b]

[1] *Max-Planck-Institut für Plasmaphysik, Wendelsteinstraße 1, 17491 Greifswald, Germany*

[2] *Spacetek Technology AG, Brüggliweg 18, 3073 Gümligen, Switzerland*

[3] *Oak Ridge National Laboratory, Oak Ridge, Tennesse 37831, USA*

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[b] See author list of Thomas Sunn Pedersen et al 2022 Nucl. Fusion 62 042022

Abstract

A novel time-of-flight mass spectrometer was operated in Wendelstein 7-X, a magnetic confinement fusion (MCF) experiment, to assess the suitability and limitations in the use for gas exhaust analysis in MCF devices. With a focus on high mass resolution sufficient for isotope separation, the permanent presence of magnetic field and a need for fast time resolution MCF presents a challenging environment for the operation of such devices.

I. INTRODUCTION

Mass spectrometers of various measurement principles are indispensable in many applications, vacuum quality monitoring and gas composition being a prominent one. Wendelstein 7-X (W7X) is an optimized modular stellarator experiment dedicated to magnetic confinement fusion research in high-temperature plasmas [TODO reference]. Time-of-flight mass spectrometers (TOF-MS) measure mass to charge ratio m/z by accelerating ions against a retarding field and measure the response time in a detector. The flight time is directly proportional to the ions m/z ratio, which allows the mass-resolved measurement of the injected ions. The IonTamer® FA (ITFA) is a novel TOF-MS <put properties here>. Possible applications of a fast high-resolution mass spectrometer in magnetic confinement fusion (MCF) research and future fusion reactors:

- Gas exhaust monitoring, especially accounting of DT fuel
- He exhaust monitoring, e.g. for divertor effectiveness and efficiency
- Impurity monitoring, e.g. for assessment of plasma chemistry and vacuum quality

II. RESIDUAL MAGNETIC FIELD INFLUENCE ON THE TOF-MS MEASUREMENT

Many mass analyzers require free-streaming charged particles, and TOF-MS share this property. Fast free streaming particles are subject to a Lorentz force in a magnetic field. While MCF employs toroidal fields with a quadrupole far field characteristics, residual fields of several mT cannot entirely be avoided at reasonable distance of the torus system. Therefore, magnetic shielding is frequently employed to reduce the residual magnetic field down to an acceptable level. Over

* georg.schlisio@ipp.mpg.de

the test duration, we successively improved the magnetic shielding in steps and document the effect below. While the residual field could not be measured in-situ, calculation of the residual field vectors were performed and the shielding structure was subjected to measurements in a test magnet setup thereafter.

III. DYNAMIC RANGE DEPENDENCE ON PRESSURE

The TOF-MS is designed for pressures up to $1 \cdot 10^{-3}$ Pa. Higher pressure means higher signal Sudden changes in pressure can lead to safety deactivation of the instrument

IV. TIME RESPONSE

Observing gas dynamics in the fusion exhaust requires a sub-second time resolution, which is often detrimental to dynamic range of instruments, as longer integration times give higher signal-to-noise ratio. The ITFA in its present hard- and software configuration has a minimum integration time of 0.1 s, which in turn already contains the average of 1000 scans.

V. MASS RANGE

The mass range of the ITFA is defined by hardware settings to 1300 u. Most of this range is of interest only for analysis of larger compounds, as found in chemistry analysis [1]. For the purpose of fusion gas exhaust monitoring, a mass range up to 100 u is mostly sufficient and a limitation of the mass range leads - due to the nature of a TOF - to significantly reduce data data footprint and lead to a speed-up, improving the time response.

VI. OBSERVATION OF ISOTOPES IN COMMON MOLECULES

While W7X does currently only run Hydrogen, and neither Deuterium nor Tritium is present in the machine, the question of deuterated and tritiated molecules poses itself in view of Deuterium-Tritium fuel foreseen for reactors. W7X is planning for Deuterium operation in the next years, Tritium will be utilized in ITER and beyond. Identifying fuel-carrying molecules and precisely accounting for fuel will be a relevant and challenging part of the fusion fuel cycle. While new developments [7, 8] promise to extract over 90% of the Tritium via direct internal recycling, the remaining mixture remains to be analyzed and monitored. Due to the unavailability of D and T in the experimental setup, simulations have been performed and are presented here along with measurements as a prediction of the TOF-MS capabilities in this regard.

VII. OTHER NOTABLE FINDINGS

During operation of the ITFA in hydrogen-dominated sampling gas a prominent mass peak at $m/Z = 3.024$ was reliably observed. This corresponds to thrice the hydrogen mass and relates to H_3^+, a molecule long known [4] and special relevance in astrophysics. According to literature, it forms with a proton transfer process $H_2 + H_2^+ \longrightarrow H_3^+ + H$ which occurs in the ITFA analyzer. This effect is well-documented [5] but not common knowledge.

VIII. DISCUSSION

Future development of the ITFA and its analysis tools are planned, with features like mass range selection.

DECLARATION OF THE AUTHORS

The authors declare that SG and LH are employed by Spacetek Technologies AG, manufacturer and marketer of the discussed ITFA.

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