## Implementing a Ramsey-type excitation to TAMUTRAP

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We have implemented a Ramsey-type excitation [1] Time-of-Flight Ion-Cyclotron-Resonance (TOF-ICR) scheme to TAMUTRAP-Penning trap [2,3]. In principle, it works in the same way as a conventional single fringe excitation [4] pattern where one measures the flight time of ions from the Penning trap to a microchannel plate detector (MCP) as a function of the quadrupole excitation frequency near the cyclotron frequency, $f_C=1/(2\pi)qB/m$.

In TOF-ICR method a small number of ions are injected into a Penning trap, cooled so that they remain in the center of the trap, and excited with a dipole excitation at magnetron frequency ($f_-$) for a certain period of time to increase the radius of the magnetron orbit. A subsequent quadrupole excitation at cyclotron frequency ($f_C$) is then applied for a certain time and amplitude to convert the low-frequency magnetron motion to the high-frequency reduced cyclotron motion. Due to the change in the rotation frequency the radial energy of ions increases which leads to a stronger axial acceleration of ions in the decreasing gradient of the magnetic field after they are extracted from the Penning trap. This results in shorter TOF of ions from the trap to an MCP detector.

In a conventional excitation scheme, one applies one continuous excitation pattern, while in a Ramsey-type excitation one uses two time-separated fringes. Fig. 1 shows the timing pattern for the one trap cycle in a Ramsey-type TOF measurement.

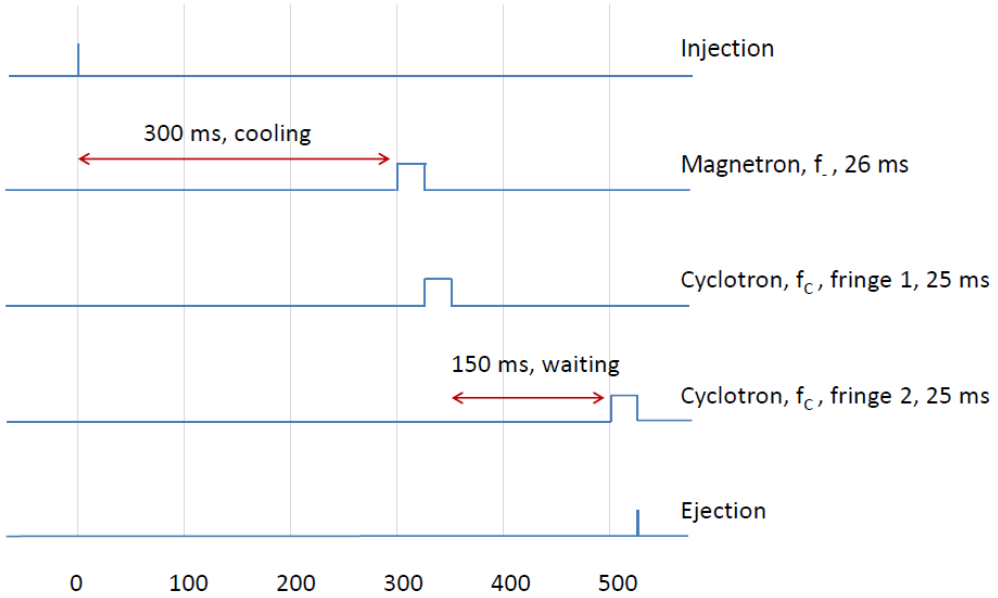


**Fig. 1**. Timing pattern used in a Ramsey-type excitation test at TAMUTRAP. The scale of the horizontal axis is ms.

A first step towards the implementation of Ramsey excitation was to increase the magnetron radius of the trapped ions. For this, a dipole excitation at the magnetron frequency, 155 Hz, RF amplitude: 5 Vpp (sinusoidal) was applied to one of the segments of the ring electrode for 26 ms (4 cycles in burst mode) using a DG1022 RIGOL function generator.

The cyclotron excitation was applied to two opposite segments of the ring electrode by using a Tektronics AFG3022B function generator in amplitude modulation mode with 95% depth. Another Rigol DG1022 generator was used to create a square wave amplitude modulation signal. This was run in the burst mode with a burst count of 1 with a 7 V amplitude and -2.5 V offset, with 2 separate triggers to create one modulation pulse per trigger. Table I shows the summary of RF generators and their settings, and Fig. 2 shows the resulting TOF pattern with using a 25-150-25 ms (On-Off-On) excitation pattern.

**Table I**. Summary of waveform generators used at TAMUTRAP for Ramsey excitation.

| Model | Type | Motion | Amplitude | Mode | Other |
|---|---|---|---|---|---|
| Rigol DG1022 | dipole | magnetron | 5 V | burst/4 | |
| Rigol DG1022 | AM | modulation | 7 V with a -2.5 V offset | burst/1 | |
| Tektronics AFG3022B | quadrupole | cyclotron | adjusted | AM 95% depth | Ramsey excitation |

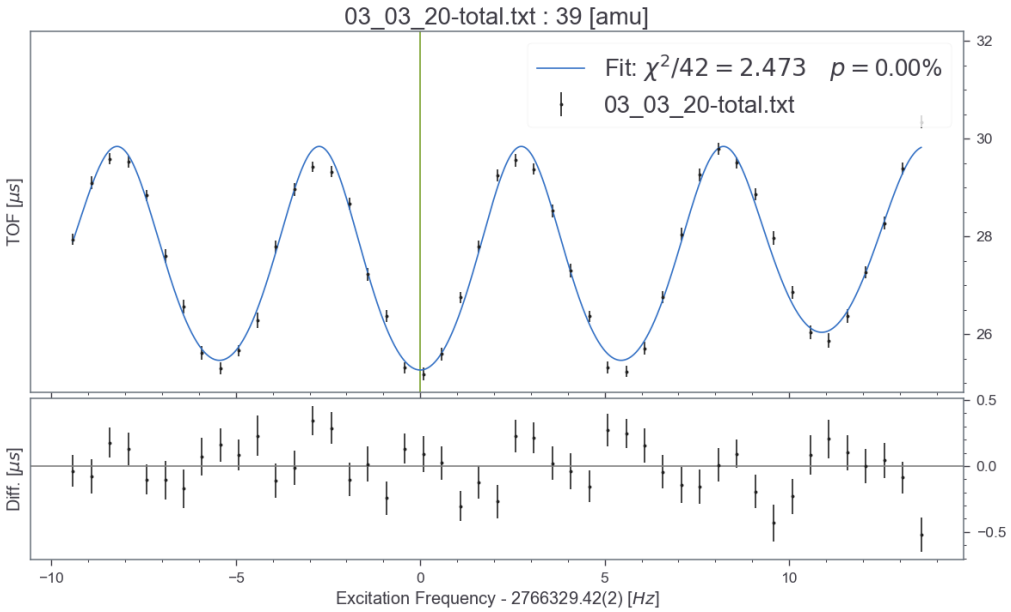


**Fig. 2**. TOF-ICR resonance curve of $^{39}$K ions obtained with a 25-150-25 ms Ramsey excitation pattern.

[1] M. Kretzschmar, Int. J. Mass Spectrom. **264**, 122 (2007).

[2] P. Shidling *et al.*, Hyperfine Interact. **240**, 40 (2019).
[3] M. Mehlman *et al.*, Nucl. Instrum. Methods Phys. Res. **A712**, 11 (2010).