Design, Characteristics and Dynamic properties of Mobile Plunger-based Frequency Tuning System for Coaxial Half Wave Resonators

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Abstract

The practical realization of a prototype of the frequency tuning system (FTS) for coaxial half-wave cavities (HWR) for the Nuclotron-based Ion Collider fAcility (NICA) injector is presented. The impact of FTS on electromagnetic parameters of copper HWR prototype is experimentally studied and discussed. The most important parameters like tuning range, tuning sensitivity, the dependence of the resonant frequency on the position of the plungers are estimated.

The effective operation algorithm of the proposed FTS is discussed and analyzed. The dynamic characteristics of FTS are investigated and showed the ability to adjust the frequency with an accuracy of about 70 Hz.

HWR and FTS overview

The present work is devoted to aspects of Frequency tuning system (FTS) design for half-wave coaxial superconductive cavities[1], which are developed for the Nuclotron-based Ion Collider fAcility (NICA) injector. These cavities (Fig.1) comprise the β=0.21 accelerating section and are operating at frequency 325 MHz.

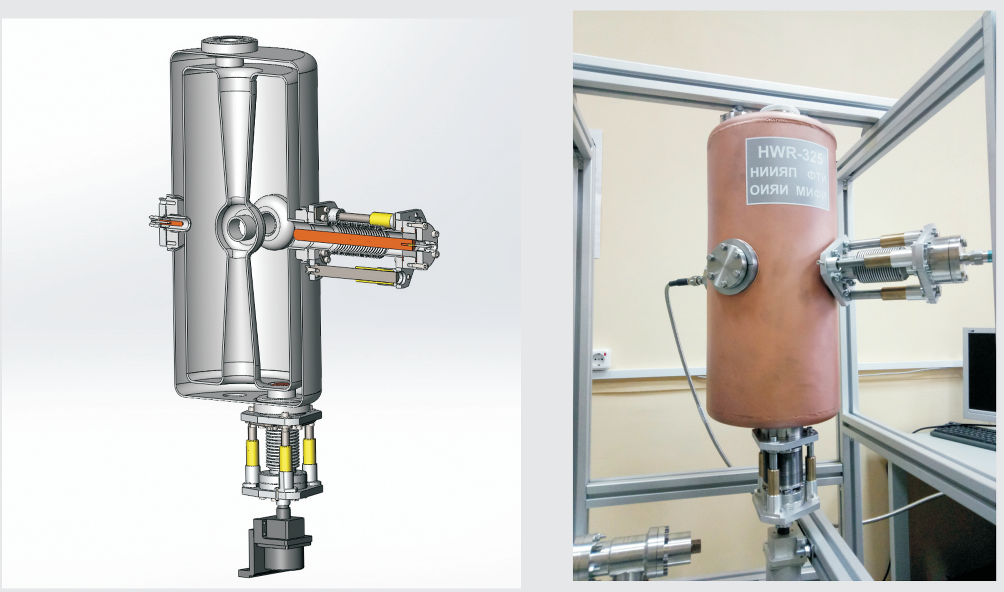

Figure 1. 325 MHz HWR cavity mode (left), fabricated copper prototype (right).

The proposed FTS is based on mobile plungers placed inside the holes in the HWR end cups (see similar systems in [2-4]). By varying of plungers' penetration depth inside the cavity volume (Fig.2) it is possible to change the effective distance between HWR end caps and tune the frequency.

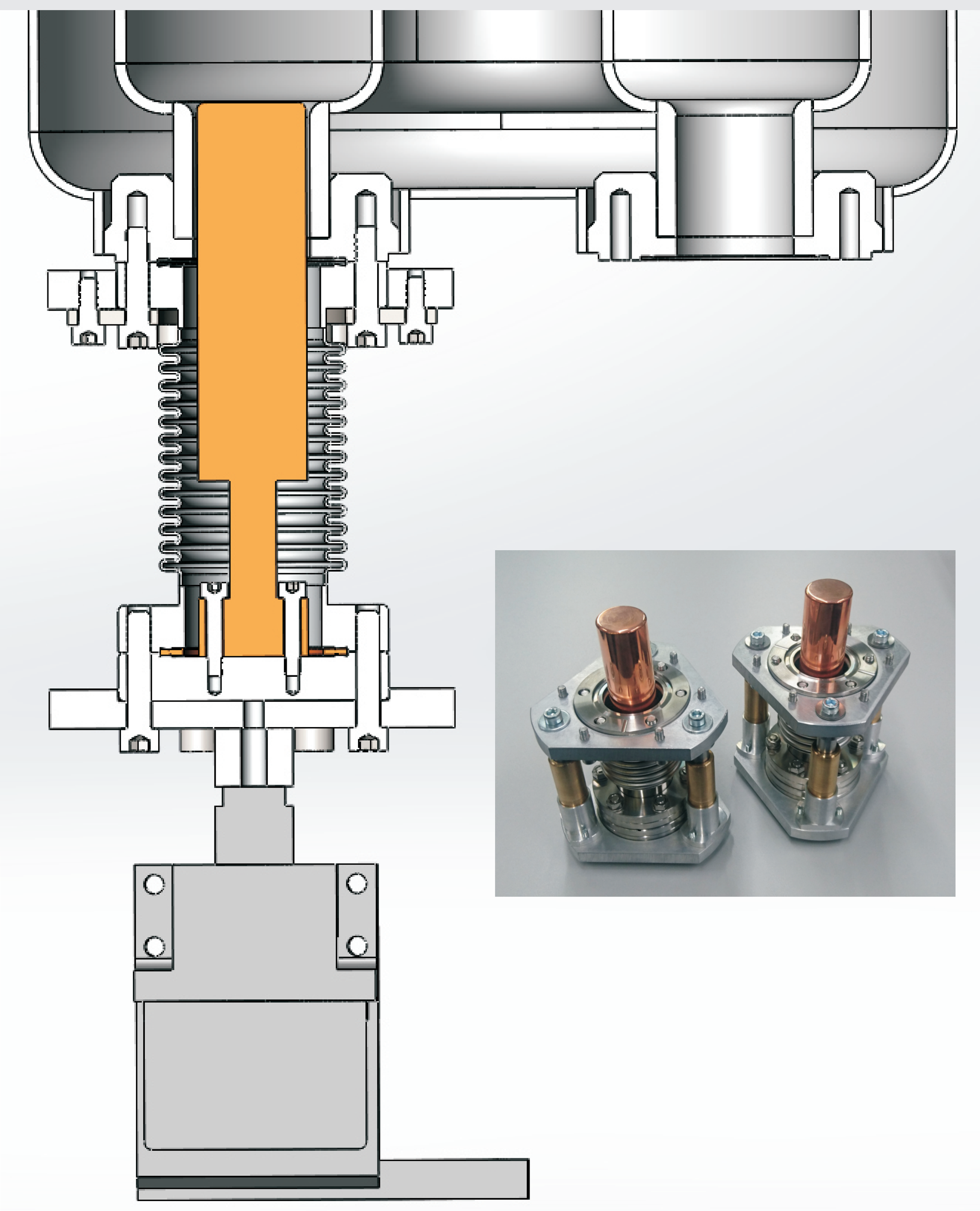

Figure 2. FTS in the one plunger configuration, (inset: fabricated copper plunger units).

FTS operation algorithms

The experimental realization of the slow FTS concept is based on a vector network analyzer (VNA) used for resonance frequency control. In a dynamic regime, the FTS should automatically compensate for the deviation of HWR resonant frequency.

Algorithm A is based on scanning using VNA a narrow frequency range and searching for resonance frequency. Within this strategy, the resonant frequency (Fig.3(a)) value is continuously measured by the VNA and processed by the Arduino controller. If the deviation of the measured value of the frequency differs from the goal frequency more than the threshold value $\Delta\nu_0$ then the stepper-motor actuator changes the plunger position to compensate for the frequency difference. The speed of the stepper motor is dependent on the deviation of resonant frequency from the goal value.

Algorithm B is based on phase measurements. In Fig.3(b) are presented typical phase spectra of reflected from the cavity signal S_{11} for plunger positions with minimal, middle, and maximal penetration depth ΔL in the cavity. Phase spectra have two extrema and can be divided into three regions: A, B, C (see Fig.3(c)). The regions A, C are characterized by a negative derivative. The middle region B (near resonance) is characterized by a positive derivative. This frequency dependence of the phase allows organizing an algorithm for frequency tuning by 3 points. The VNA operates much faster when it is used for phase measurements only in three fixed frequencies. The central point is corresponding to the goal frequency. The lateral points are distanced from goal frequency by ±1 kHz. If the current frequency is far from the goal (i.e. points are locating in regions A or C), synchronous comparison of the phase of central point with the goal value, as well as the phases of the lateral points with each other, allows determining the direction of plunger movement with a maximal velocity of stepper motor. With such a movement, the three points move to region B, where the phase difference between the lateral points changes sign.
After this event it is possible to directly compare the phase of the central point with the phase at the goal frequency, avoiding ambiguity. The speed of the stepper motor is also may be ranged depending on deviation from the goal phase.

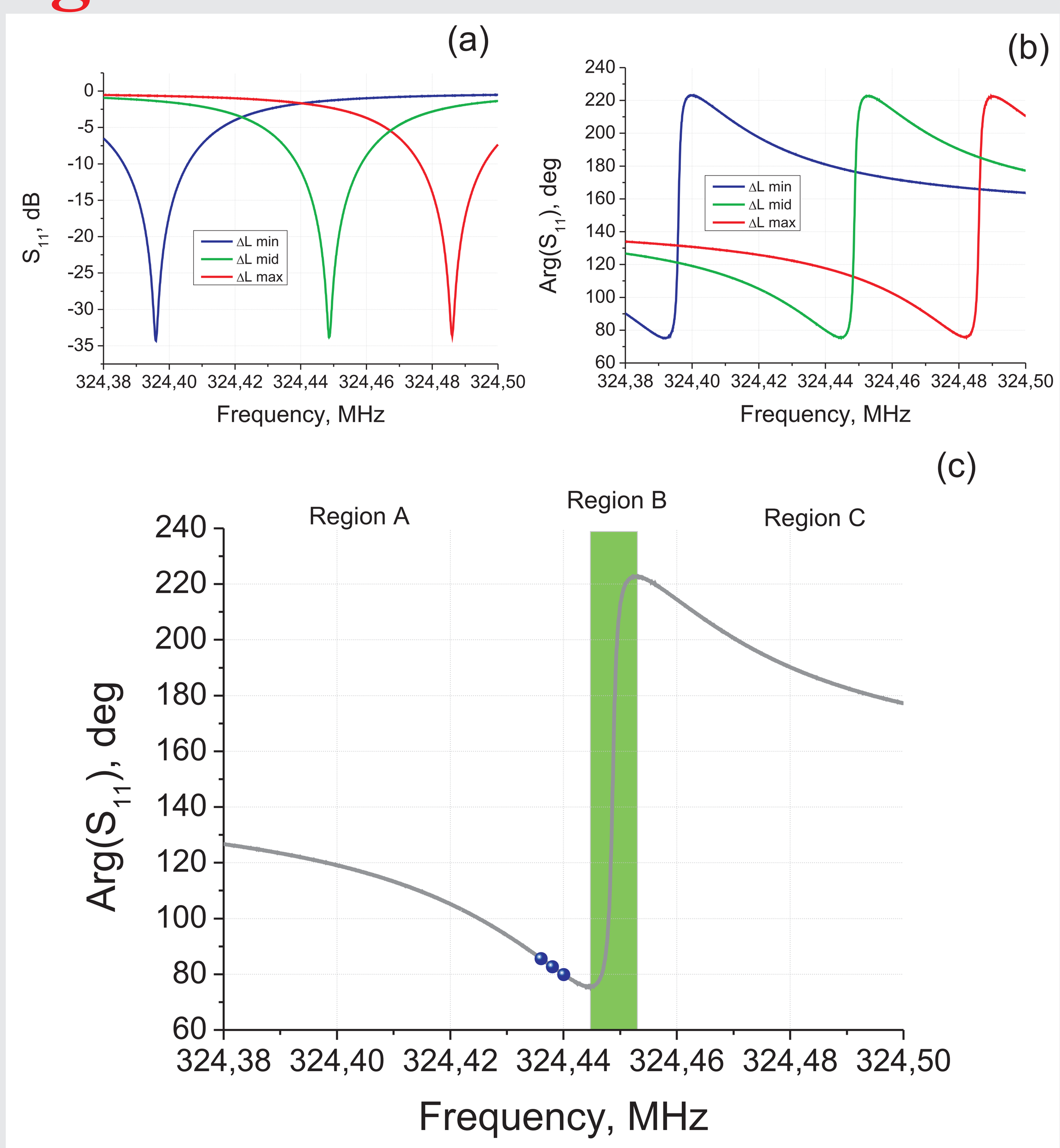

Figure 3. (a) Frequency dependencies of reflected from the cavity signal S_{11} for plunger positions with minimal, middle, and maximal penetration depth ΔL; (b) the same for S_{11} phase; (c) 3 points positions in Algorithm B.

FTS static and dynamic properties

Results of typical measurements of the resonant frequency of the cavity for various penetration depth ΔL are presented in Fig. 4.

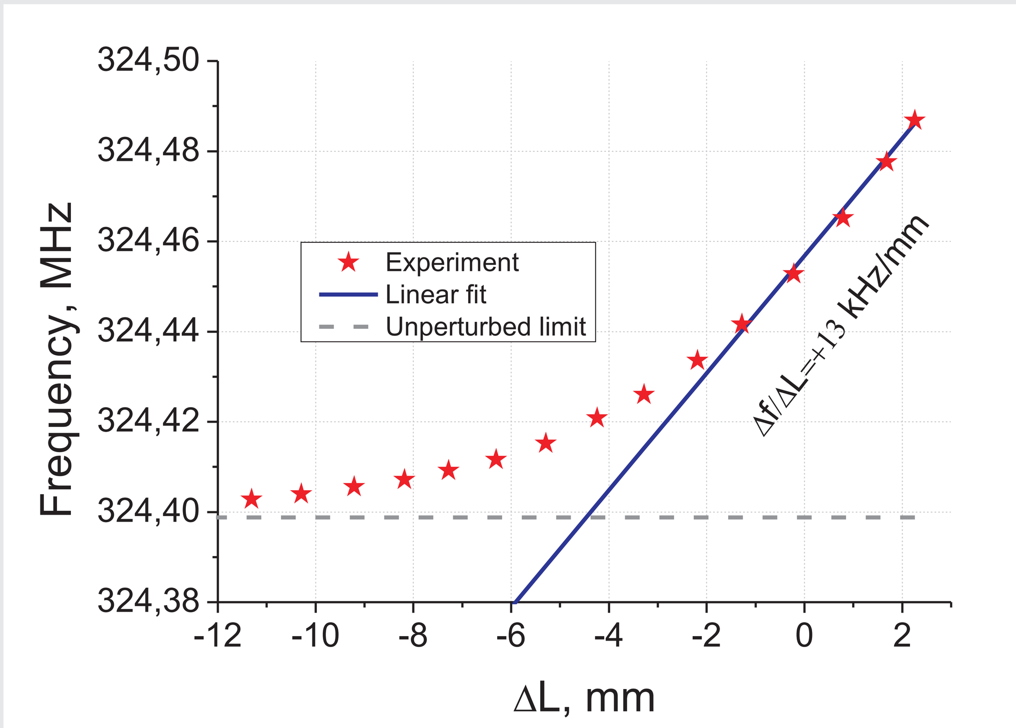

Figure 4. Experimentally measured resonant frequency vs plunger penetration depth ΔL.

From Fig.5 one can see the monotonic dependence of resonant frequency on plunger penetration depth. The maximal frequency sensitivity is equal to Δf/ΔL =+13 kHz/mm.

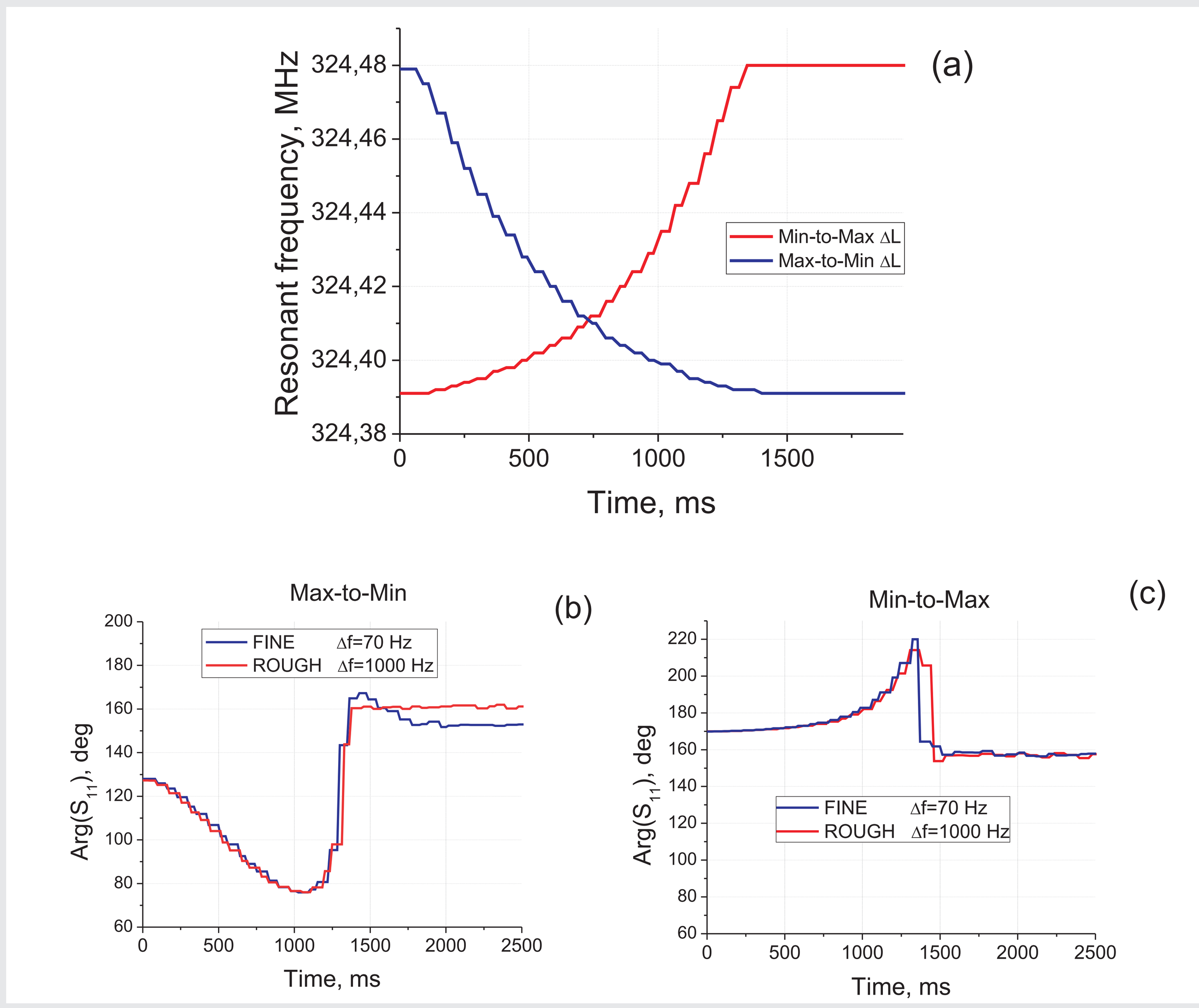

Figure 5. (a) The FTS dynamic response depending on the frequency deviation sign for Algorithm A, and (b-c) for Algorithm B.

The typical dynamic behavior of FTS when the frequency deviation is close to the full tuning range (about 70 kHz) is presented in Fig.5 (a-c). Due to the nonlinearity of sensitivity Δf/ΔL, the response is depending on the frequency deviation sign.
The stabilization time in all cases is about 1.3 s. Using Algorithm A the minimum threshold value $\Delta\nu_0$ the minimum threshold value for stable FTS operating is about 1 kHz. A much better tuning level is possible when the FTS is operating using Algorithm B. The minimum threshold value, in this case, is Δf_0=70 Hz, which is close to the frequency adjustment limit df caused by minimum possible plunger movement dl=5 μm for the proposed slow frequency tuning system.

Refrerences

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