ELECTROMAGNETIC SCRF CAVITY TUNER*

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Abstract

A novel prototype of SCRF cavity tuner is being designed and tested at Fermilab. This is a superconducting C-type iron dominated magnet having a 10 mm gap, axial symmetry, and a 1 Tesla field. Inside the gap is mounted a superconducting coil capable of moving ± 1 mm and producing a longitudinal force up to ± 1.5 kN. The static force applied to the RF cavity flanges provides a long-term cavity geometry tuning to a nominal frequency. The same coil powered by fast AC current pulse delivers mechanical perturbation for fast cavity tuning. This fast mechanical perturbation could be used to compensate a dynamic RF cavity detuning caused by cavity Lorentz forces and microphonics. A special configuration of magnet system was designed and tested.

INTRODUCTION

A superconducting tuner relates generally to superconducting magnets and more particularly to radio frequency tuners for use in linear particle accelerators. Technology in superconducting linear accelerators has been substantially improved over 10 years. Niobium superconducting radio frequency cavities (SCRF) are the main element of linear accelerators. Future linear accelerators and colliders ILC [1], TESLA [2], XFEL [3], Project-X [4] need to explore high (25 – 35 MV/m) electrical field gradient cavities with the possibility of cavity tuning during accelerator operation. SCRF cavity deviations from a resonant frequency depend on the cavity geometric changes caused by manufacturing errors, cool down shrinkage, pressure fluctuation of LHe, Lorentz forces, and external mechanical vibration.

There are two types of cavity detuning effects, slow and fast. Typically, slow correction of the cavity resonant frequency uses a mechanical tuner with a stepper motor drive. A drive shaft to the tuner mounted on the low temperature cavity is used if the stepper motor is placed outside the cryostat at room temperature [5]. It increases the heat leak and the inherent backlash of the system. Tuners require special reliable stepper motors that operate at low temperature to operate within the cryostat [6]. Complicated mechanics also drive the cost of these devices. Piezoelectric or magnetostrictive tuners are used for fast cavity tuning to eliminate low and high frequency vibration [7]. Nevertheless, at that time no complete technological solutions existed for cold SCRF tuners [8].

So, the ideal tuner should provide simultaneously slow and fast tuning with high device reliability at liquid helium temperature.

ELECTROMAGNETIC TUNER

The G.W. Foster idea to use Lorentz forces between two superconducting coils to tune a superconducting resonant cavity frequency in slow and fast modes was realized in the electromagnetic SCRF tuner device shown in Fig. 1.

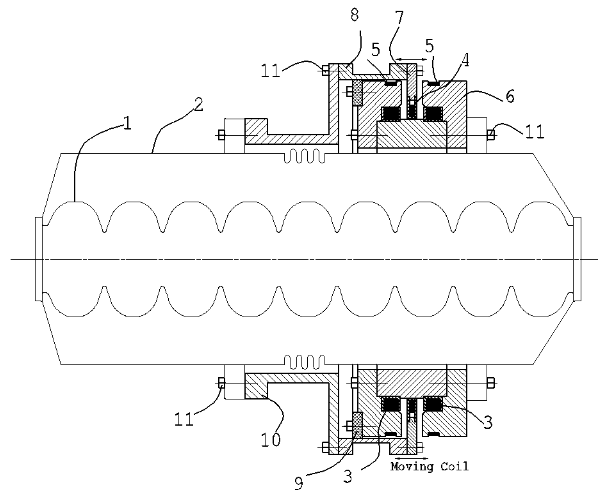

Figure 1: Electromagnetic Tuner cross-section.

Electromagnetic Tuner Design

The electromagnetic tuner includes two sets of superconducting coils combined with a ferromagnetic yoke in one assembly. The tuner specification given in Table 1.

Table 1: Electromagnetic Tuner Specifications

Parameter	Unit	Value
Maximum field in main coils	T	2.1
Maximum field in moving coil	T	1.25
Maximum field in bucking coils	T	0.28
NbTi superconductor diameter	mm	0.26
Superconductor critical current at 4.2K and 3 T field	A	70
Main coils current	A	33
Main coil number of turns		300
Moving coil current	A	30
Moving coil number of turns		80
Electromagnetic force	kN	1.5

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The electromagnetic tuner connected to the SCRF cavity (1) through cavity LHe vessel (2) flanges by connection elements (7-11). The first – main set of coils (3) generates a stationary magnetic field. The second – moving and bucking coil set (4) provides the moving coil and cavity motion in the longitudinal direction. Bucking coils (5) and the iron yoke (6) eliminate the magnet system fringe field. Each coil set has current leads are powered from separate power supplies as shown in Fig. 2

The total current of this assembly going through the magnet cross-section at any moment of operation is equal zero. It eliminates the tuner outer fringe field to an acceptable level for SCRF cavity operation.

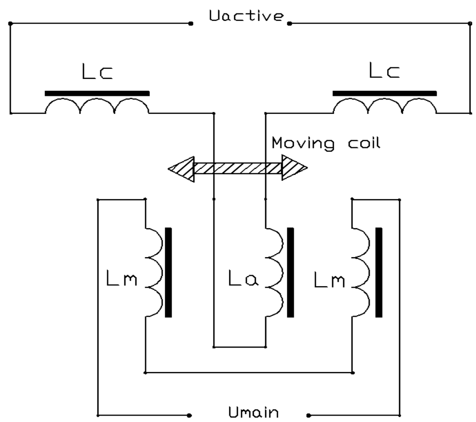

Figure 2: Tuner scheme.

DC current powers the tuner main coils Lm. These coils produce the radial axial symmetric magnetic field in the magnet gap. The moving coil La when excited under Lorentz forces moves along z-axis. Fig. 3 shows the field flux lines when both coil systems are powered. The yoke thickness is chosen to avoid the iron saturation at peak currents and eliminate fringe fields in the cavity area.

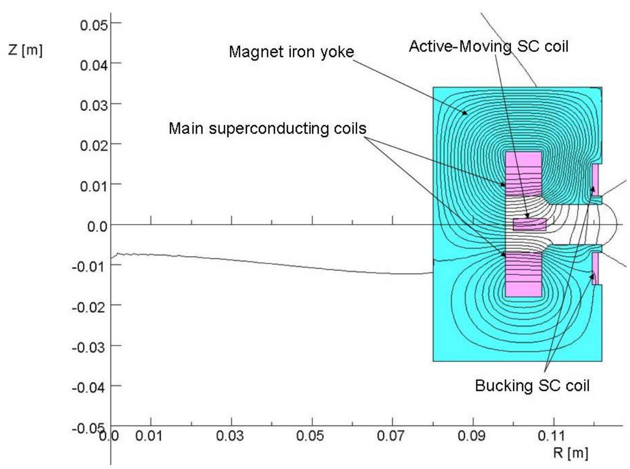

Figure 3: Magnet cross-section and flux lines.

It should be noted that the magnetic field radial component and corresponding Lorentz force applied to the moving coil is constant and does not depend on the moving coil position.

TUNER TEST RESULTS

Tuner Fabrication and Mechanical Test

The tuner superconducting coils were wound inside aluminum alloy bobbins and then vacuum impregnated with epoxy. The tuner was assembled within a 3.9 GHz cavity as shown in Fig.1. To simplify the test, a copper 3.9 GHz RF cavity was used. This was a mechanical prototype of a third harmonic cavity [9].

The mechanical and electrical properties of the cavity assembled with the helium vessel were investigated. This assembly was cooled down to a liquid Nitrogen temperature and the mechanical system spring constant (2.3 kN/mm) and the cavity resonance frequency shift versus cavity length coefficient (2.2 MHz/mm) were measured.

Measurement Stand

Cavity-Tuner assembly has been tested at the FNAL/TD vertical cryogenic test stand [10]. The instrumentation used to test parameters of the tuner were AC and DC programmable power supplies, Network Analyzer, 3.9 GHz RF power source, an analog phase detector and PXI/LabView DAQ (see Fig. 4).

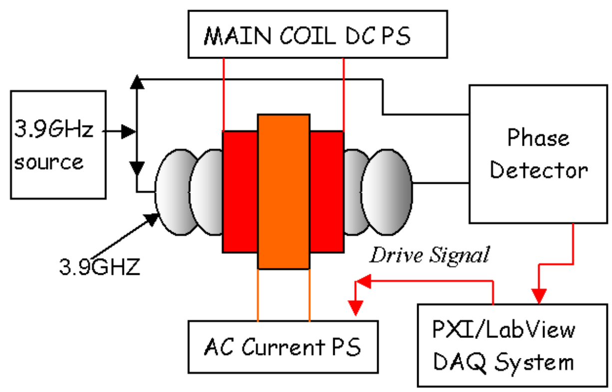

Figure 4: Phase detection scheme.

Tuner Slow Mode of Operation

In a slow mode of operation the tuner force applied to the cavity changes the cavity length and corresponding cavity frequency proportionally to the value of currents going through the main and active coils (see Fig. 5).

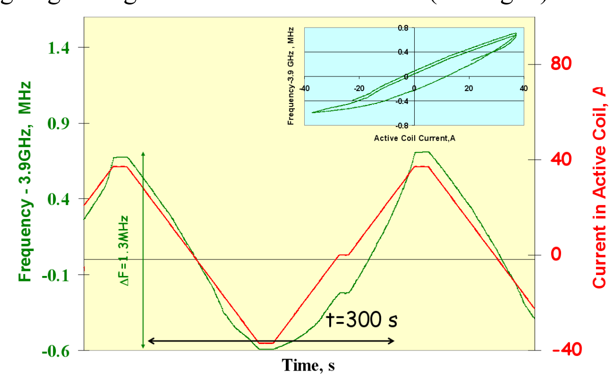

Figure 5: Cavity slow tuning (Im = 30 A, Ia = ± 37 A) .

Cavity resonant frequency was measured with the Network Analyzer connected through GPIB to PXI DAQ. Maximum cavity tuning applied to cavity during experiment was ± 650 kHz, with current on the main coil Im = ± 30 A and Ia = ± 35 A. To change the tune of the cavity within the range of ± 650 kHz, the tuner changes the cavity length of ± 300µm and applies a force of ± 680 N. A saw-tooth current is applied to the active coil (Im = 30 A) to change the cavity frequency as shown in Fig. 5.

Tuner Fast Mode of Operation

To study parameters of fast tuner capabilities we run the cavity in a continuous wave operation mode with small power signal from the 3.9 GHz source. Dynamic cavity tune effect has been measured using the standard technique of measuring phase shift between forward and transmitted power (see Fig. 4). A well established technique for cavity Lorentz force compensation used the method of exiting mechanical motion into the cavity from the tuner before the RF pulse in one of the mechanical cavity resonances [11]. We measured (see Fig. 6) the cavity-tuner system response to the different frequencies of sine wave currents used to drive the moving coil.

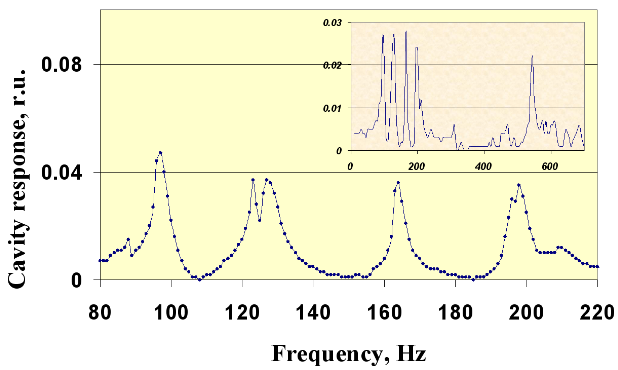

Figure 6: Cavity-tuner system transfer function. Active coil exited with sine wave current drive signal. Frequency of drive signal swept from 20 Hz up to 700 Hz.

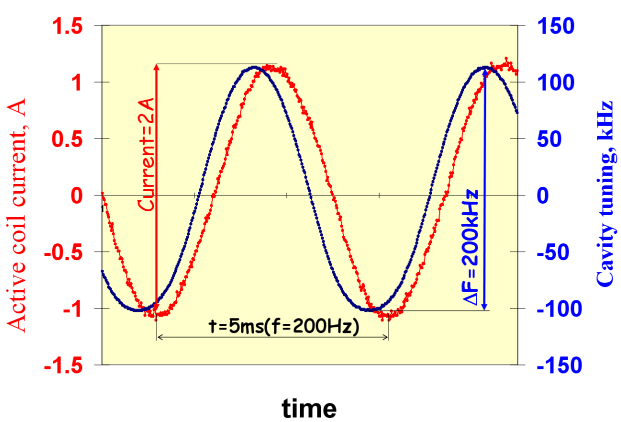

Figure 7: Tuner fast mode of operation. The active coil current is (f = 200 Hz and Ia = 2A), Im = 30 A .

One can see that the cavity-tuner system has mechanical resonance frequencies of 95 Hz, 130 Hz, 165 Hz, 200 Hz, and 550 Hz. The response of the cavity when tuner (active coil) is driven with the sine wave current at 200 Hz (Ia = 2A, Im = 30A) is presented in Fig. 7. The stroke of active coil motion is close to 100 µm. The stroke at least an order of magnitude larger than could be achieved with piezo or magnetostrictive tuner.

CONCLUSION

The novel SCRF Electromagnetic Superconducting Tuner was designed, fabricated, and tested at Fermilab. This tuner has following advantages over other tuner types:

- simple configuration and low cost
- large and linear tuning force
- combined in one device slow and fast tuning mode of operation
- reliable parts and components
- fast response
- regulated form of tuning force
- very low fringe field.

The next step in the Electromagnetic Tuner R&D will be to update this design for 1.3 GHz SCRF cavities used in most future accelerators.

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