A TUNER FOR A 325 MHZ SRF SPOKE CAVITY

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Abstract

Fermilab is developing 325 MHz SRF spoke cavities for the proposed High Intensity Neutrino Source. A compact fast/slow tuner has been developed to control Lorentz force detuning and compensate for liquid Helium pressure fluctuations. The tuner design and results of warm tests of the first prototype are presented.

INTRODUCTION

The Fermilab High Intensity Neutrino Source Linac R&D program is building a 30 MeV superconducting H^- linac. The early stages of the linac employ superconducting spoke cavities operating at a frequency of 325 MHz and a temperature of 4.5 K[1,2].

As with other pulsed superconducting cavities, for example the widely used 1.3 GHz Tesla style elliptical cavities, each spoke cavity will be equipped with slow tuner to compensate for static detuning and a fast tuner to compensate for the dynamic detuning due to the Lorentz force. Like the Tesla cavities, the slow tuner for the spoke cavities uses a stepper motor while the fast tuner employs piezo actuators.

In contrast with Tesla style cavities, the size of the 325MHz cavity and the planned operating temperature makes the resonant frequency more sensitive to fluctuations in liquid helium pressure. At the same time, the cavity walls are considerably stiffer than a Tesla style cavity so the tuner must be capable of applying stronger forces to the cavity flanges than Tesla style tuners. Furthermore the planned optics for the HINS linac provides only limited space for a tuner.

The combination of these three factors makes the design of a suitable tuner a considerable challenge.

TUNER REQUIREMENTS

The tuner must be able to compensate for the following effects.

- Static variations in the resonant frequency of the cavities due to manufacturing tolerances.
- Dynamic detuning of the cavities by the Lorentz force during the RF pulse.
- Slow variations of the cavity resonant frequency due to fluctuations in the pressure of the surrounding 4.5K helium bath.

The primary factors that drive the design of the tuner are the following:

-The spring constant of the SSR1cavity (20N/um);

-The tuning sensitivity of the cavity (560Hz/um);

-The limited space available between the end of the cavity and other beam line components (26 mm).

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Given the manufacturing tolerances for the cavities, the tuner must be able to statically retune the cavity over a range of 200 kHz centred on the nominal operating frequency of 325 MHz.

Based on simulations, at an accelerating gradient E_{Acc} = 10 MV/m, the Lorentz force is expected to detune the cavity by between 200 and 400Hz, during a 800us “flat-top” RF pulse. This detuning is significant when compared to the loaded width of the cavity resonance of 200Hz. If the Lorentz force detuning is not compensated, additional RF power will be required to achieve the desired accelerating gradient.

At the planned operating temperature of 4.5 K slow fluctuations in the pressure of the surrounding liquid He bath pressure can change the resonant frequency of the cavity over periods of several minutes. An ANSYS model [3] estimated the sensitivity to be: $\Delta f/\Delta P$=30 kHz/atm. The cryogenic system will be able to regulate the helium pressure to within ±0.25psi. Pressure variations of this magnitude can shift the resonant frequency by up to 500Hz.

Furthermore, the tuner must be able to limit the forces applied to the cavity during cool-down. At one step during the cool-down procedure, the cavity will be under vacuum at room temperature while the surrounding helium vessel will be pressurized with up to 1.5atm of helium gas. If the cavity flanges were not constrained by the safety rods, the plasticity limit of the cavity walls could be exceeded and the cavity could be irreversibly de-tuned.

Finally, in event the cavity should fail, the tuner must be able to statically detune the cavity by 200 kHz to limit any beam-cavity coupling.

TUNER DESIGN

The major elements of the tuner are shown in Figure 1.

Although the cavity could in principle be tuned from only one end, both ends of the cavity will be equipped tuners. The dual tuners allow the mechanical loads to be applied symmetrically and provide redundancy.

A stepper motor controls the position of each slow tuner arm via a harmonic drive assembly and screw mechanism. The arm is pivots on bearings attached to the helium vessel wall. The position of the pivot was chosen to provide a ratio of 5:1 between the displacements of the stepper motor and the cavity flange.

Motion of each arm is transmitted to the respective cavity flange by two piezo actuators. To accommodate the large forces required to compress the cavity two actuators were used at each end.

To deliver the required static tuning range of -50 kHz to -200 kHz, each slow tuner must displace its respective

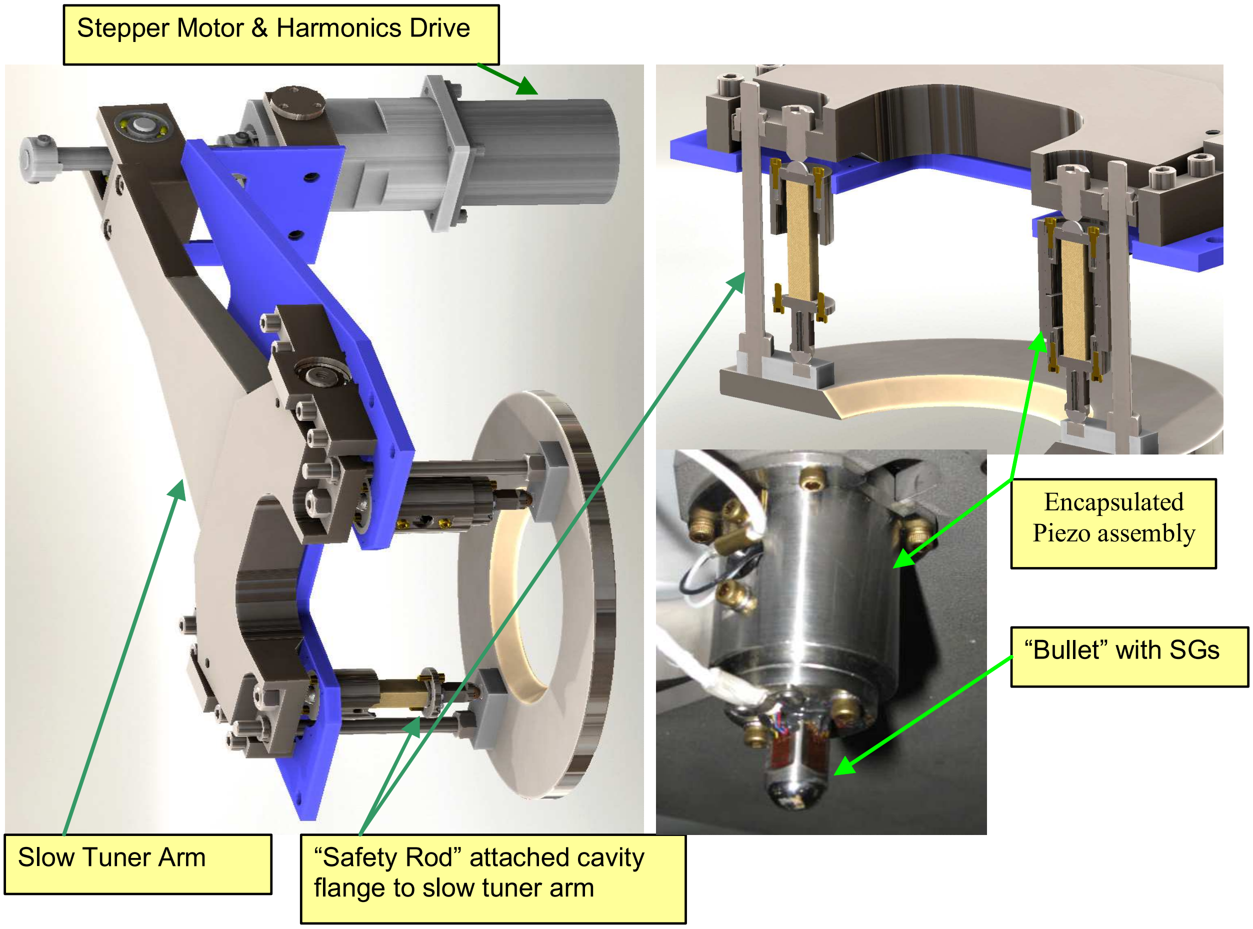

Figure 1: Details of SSR1 tuner design.

flange by between 45 and 180um. Over this range, the static load on each piezo will change by ~2kN or 50% of piezo blocking force. To ensure that the load on the piezo remains between 20% and 80% of the blocking force, the tuner is designed to always "push" the cavity, i.e., the tuner is designed to apply compressive forces to the cavity flanges across the entire tuning range.

Actuators were selected to provide the cold stroke of 6um while working against the cavity spring constant. To avoid shear forces on the actuators and to simplify the connection with the arms, the piezo-stacks have been encapsulated in custom stainless steel housings.

Important tuner parameters are summarized in below in Table 1.

In parallel with the actuators, two safety rods are installed at each end. The rods are designed to limit the forces on the cavity during cool-down.

During warm testing or cold operation, the force applied to the cavity flange by each actuator can be monitored using a stainless steel "bullet" [4] installed between the actuator and the flange. Each bullet is a custom load cell consisting of a stainless steel cube instrumented on four sides with strain gauges (fig.1). The gauges measure the compression and torsion of the cube as the actuators apply force to the flange. A fifth unloaded strain gauge serves as a temperature compensated reference.

The tuner has been designed so that it can be assembled and tested as an independent unit prior to being mounted on the cavity. Following testing, the assembly is bolted to the cavity Helium vessel and the safety rod limits and initial piezo preload are set using adjustment screws.

TEST RESULTS

Figure 2 shows two prototype tuners installed on the helium vessel of an SSR1 cavity during recent warm tests.

Slow Tuner Results

To evaluate the performance of the slow tuner, the resonant frequency of the cavity was monitored using a network analyzer as the stepper motors were operated. During motor operation, the forces on the cavity flanges were monitored by the bullets attached to each piezo actuator and the displacement of the arm and actuators were measured with dial gauges.

The dial gauge measurements with the first prototype showed that for a given stepper motor displacement, the cavity flange was displaced by only approximately half of that expected. At the time of the tests, the final hardware required to mount the tuners on the helium vessel was not available and a temporary solution was employed. Although flexure of temporary mounting arrangement may be the source of some or all of discrepancy, additional stiffening of the tuner components and improvements in the mounting arrangement are planned.

Table 1: Tuner Design and Performance Parameters.

Parameter	Design	Measured
Cavity Spring Constant (N/mm)	20	26
Cavity Sensitivity (Hz/N)	540	~500
Stepper Motor Sensitivity (Hz/Step)	1.8	0.9
Piezo Sensitivity (Hz/V)	120	60
Arm Mechanical Advantage	5:1	10:1
Maximum Piezo Load (N)	3200	2200
Minimum Piezo Load (N)	800	200
Tuning Range (kHz)	200	200
Piezo Preload (N)	400	400
Preload/Blocking Force (%)	10	10
Piezo Length (mm)	40	40
Piezo Cross Section (mm^2)	10*10	10*10
Maximum Piezo Voltage (V)	200	120
Actuator Stroke (um) at 300K	50	-----
Number of Piezo Per Flange	2	2
Stepper Motor Current	5	1
Harmonic Drive Ratio	1:100	1:100
Steps Per turn	35k	35k
Pressure Sensitivity, kH/atm	30	----
Cavity Frequency(nominal), MHz	325	-----
Cavity Width (Hz) at 4.5K	400	-----
Cavity Operating Temperature	4.5K	-----
Lorentz Force Detuning, Hz	>400	-----
Accelerating Gradient, MV/m	10	-----
Pulse Length , us	800	-----

Figure 3 shows the change in the cavity frequency as a function of the force applied to the flanges. Even with the unplanned flexure of the assembly, the tuner can still adjust the resonant frequency of the cavity over the target range of 200 kHz while the load on the actuators does not fall outside the safe operating range of 20% to 80% of the piezo blocking force. To within 5% over the design range, the frequency shift is a linear function of the force on the flanges.

Figure 4 shows the percentage difference between the forces exerted by each of the individual piezos as a function of the average load exerted on the flange by all piezos over the design range of piezo loads. If the static load on the four piezos is not uniform, the forces exerted by the cavity walls could exceed the blocking force on one or more of the actuators. This could degrade the dynamic performance of the tuner. In these measurements, the maximum deviation of any individual actuator from the mean does not exceed 15 % and over most of the range is less than 10%.

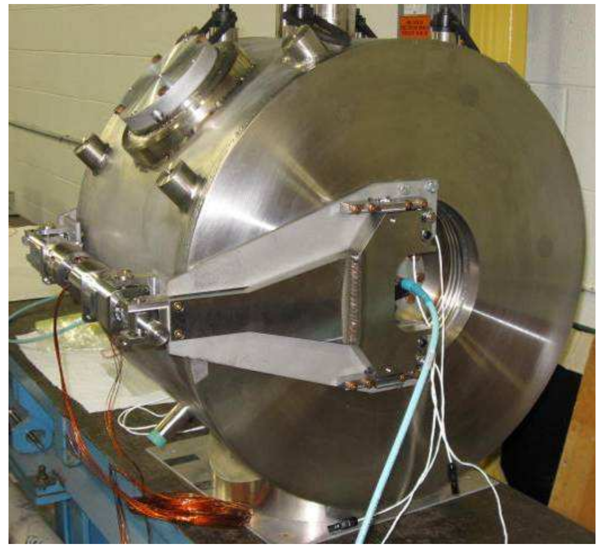

Figure 2: SSR1 cavity dressed into helium vessel with 2 tuners installed on both sides of vessel.

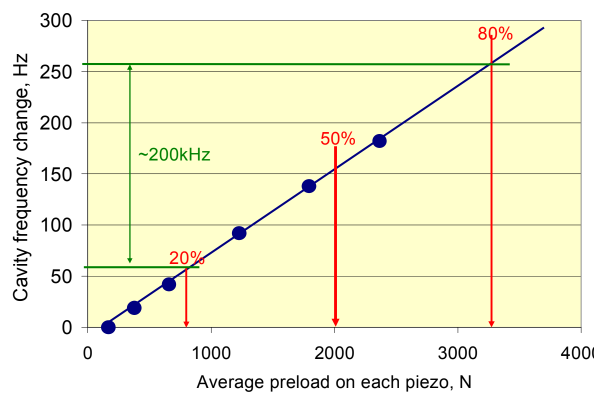

Figure 3: Cavity Frequency Shift as a Function of the Force on the Flanges

Fast Tuner Results

The dynamic performance of the tuner was evaluated by measuring the transfer function between the piezo actuator voltage and the cavity phase at the peak of the resonance.

Voltages were digitized over a two second interval using a 500 MHz bandwidth digital oscilloscope.

The actuator modulates the resonant frequency of the cavity at the piezo drive frequency leading to detectable side bands in the cavity probe signal. The transfer function is given by the ratio of the amplitude of the side bands to the amplitude of the piezo drive signal.

The magnitude and phase of the transfer function are show in Figures 5 and 6 respectively. The magnitude shows a number of prominent peaks corresponding to mechanical resonances of the cavity-tuner system. The cavity was driven with a 20 dBm sine wave at the resonant frequency of 324.9 MHz while a 100 V peak-to-peak sinusoidal voltage was applied to the piezo actuators. The frequency of the piezo drive signal was stepped from 1 Hz to 1k Hz in 1 Hz increments. During each step, the cavity drive voltage, the cavity probe voltage, and the piezo drive.

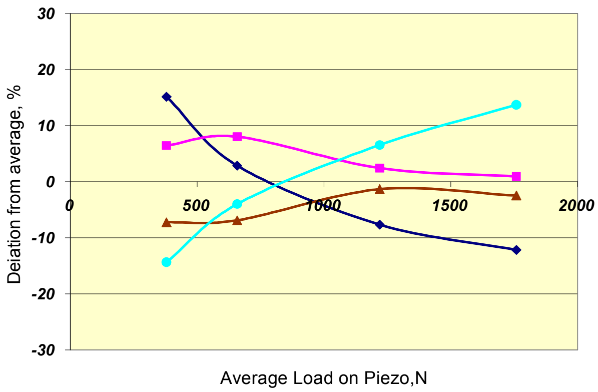

Figure 4: Percentage Piezo-to-Piezo Load Variation as a Function of the Average Load Exerted on the Flange.

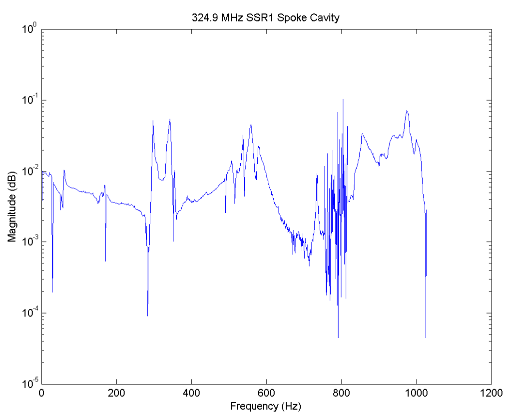

Figure 5: Transfer Function of SSR1/tuner system: magnitude response.

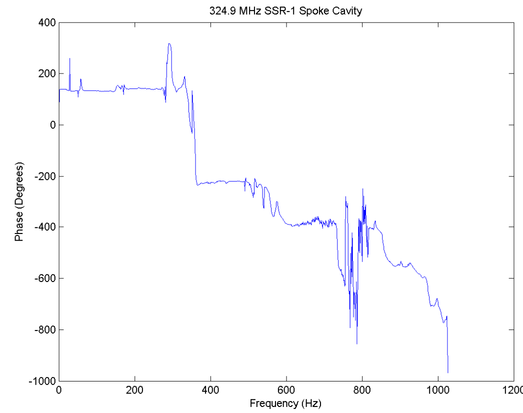

Figure 6: Transfer Function of SSR1/tuner system: phase response.

While the system may have mechanical resonances in addition to those that lead to peaks in this transfer function, vibrations at those resonances will not affect the tune of the cavity during operation.

SUMMARY

A compact fast/slow tuner has been developed for 325 MHz SRF spoke cavities for the proposed High Intensity Neutrino Source at Fermilab. The design of the tuner has been described and results of warm measurements of the static and dynamic performance of the first prototype are presented.

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