HIGH POWER TEST OF ROOM TEMPERATURE SPOKE CAVITIES FOR HINS AT FERMILAB *

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Abstract

The High Intensity Neutrino Source (HINS) R&D program at Fermilab will build a new 65 MeV test linac to demonstrate new technologies for application in a high intensity hadron linac front-end. The HINS warm section is composed of an ion source, a radio frequency quadrupole, a medium energy beam transport and 16 room temperature Crossbar H-type (RT-CH) cavities that accelerate the beam to 10 MeV (β=0.1422). The RT-CH cavities are separated by superconducting solenoids enclosed in individual cryostats. Beyond 10 MeV, the design uses superconducting spoke resonators. In this paper, we illustrate the completion of four RT-CH cavities and explain latest modifications in the mechanical and radio frequency (RF) designs. Cavities RF measurements and tuning performed at Fermilab are also discussed. Descriptions of the HINS R&D Facility including high power RF, vacuum, cooling and low level RF systems will be given. Finally, the history of RF conditioning and the results of high power tests of RT-CH cavities will be discussed.

INTRODUCTION

Fermilab is considering an 8 GeV superconducting H-linac with the primary mission of enabling 2 MW beam power from the 120 GeV Fermilab Main Injector for a neutrino program [1]. The front end linac in the energy range from 10 MeV to 400 MeV is foreseen as based on 325 MHz superconducting spoke resonators. New paradigms introduced into the front end design include the adoption of short, high field SC solenoids as primary lattice focusing elements and a low energy transition at 10 MeV from RT to SC RF acceleration. The HINS R&D program is underway to demonstrate these concepts in a 65 MeV prototype linac [2].

Our studies show that the most appropriate RT accelerating structure in the energy range 2.5-15 MeV is a CH type cavity [3, 4] operating at 325 MHz. We have successfully fabricated, fully dressed and high power tested the first three RT-CH resonators. The next one is now ready for high power tests. We are currently fabricating the remaining twelve resonators.

CAVITY RF DESIGN

The RF design of the RT-CH cavities is reported in [2, 3]. In order to accelerate the manufacture of the remaining twelve cavities, five different designs are used instead of twelve. So there are 2-3 identical cavities in each of the five groups. Due to the reduction in the overall efficiency of acceleration, the power loss in the warm section is increased by 2%.

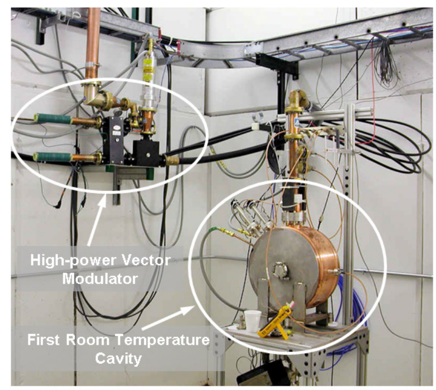

Figure 1: Cavity completed with coupler, tuners, cooling pipes, vacuum, and vector modulator.

RF POWER SYSTEM AND TEST STAND

The cavity under test is completed with a power coupler, a pair of motor-driven tuners (now reduced to one) and cooling pipes and is mounted on a test stand sitting inside a cavity test cave for radiation shielding purpose (See Fig.1). This cavity assembly is then leak-checked with helium and is connected to low conductivity water (LCW), vacuum pumps and gauges, high power RF directional coupler and cable, and low-level RF (LLRF) signal cables.

RF power is supplied by a 325 MHz 2.5 MW Toshiba E3740A klystron which is protected by a 2.5 MW circulator (See Fig.2). Two RF power lines, 25 kW and 250 kW, are available for the cavity test cave. The 25 kW line was used in the test.

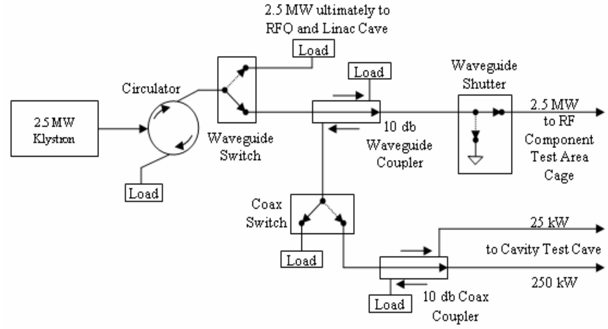

Figure 2: RF power and distribution system diagram.

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LCW is maintained at a temperature of approximately $97.0 \pm 0.5\ ^0$F by a heater feedback circuit and at a flow rate of about 1 gal/min. A turbo molecular pump is attached to the cavity for pump-down, after which an ion pump alone can maintain cavity vacuum. An ionization vacuum gauge and the ion pump current provide monitors of the vacuum pressure. A base pressure of 2×10^{-7} Torr before application of RF power was considered acceptable for beginning power tests.

Reflected power from the cavity, vacuum pressure, and water flow rate are part of the fast interlock system which is capable of inhibiting the RF power to protect the cavity assembly and the RF power system from being damaged in case of abnormal behavior.

HIGH POWER TESTS

The first three of the sixteen RT-CH cavities have been successfully RF conditioned and tested. These tests include measuring the tuning range provided by motor-driven plunger tuners and deducing the cavity resonant frequency sensitivity to coolant temperature and RF power level. Detail is described in this section.

RF Conditioning

The RF conditioning of RT-CH#1 was done by gradually increasing the RF power to the conditioning target, 8 kW, 3 ms and 2 Hz. Multipacting was observed at several power levels. The cavity was allowed to pump down overnight in case of persisting multipacting behavior. Vacuum trips occurred occasionally when power or pulse length increase; this is normal behavior resulting from high emission inside cavity due to imperfections such as unclean surface. This cavity took a total of 34 hours of RF power to complete conditioning.

The second cavity, RT-CH #2, was baked for 4 days at 300 ^{0}F before conditioning. The target for this cavity is 13.5 kW, 3.5 ms and 2 Hz. Although multipacting and vacuum trips were still observed, the total conditioning time was significantly shortened to 6 hours plus one overnight pump down. It is believed that the baking contributes to this improvement.

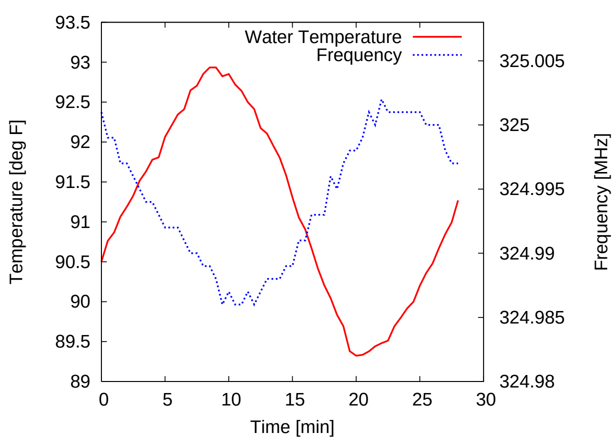

Figure 3: Cavity resonant frequency measured against coolant temperature.

Temperature Dependence of Resonant Frequency

Temperature dependence of cavity resonant frequency was studied for RT-CH #1 at zero power. The temperature of LCW was measured with a temperature probe about 1 m upstream from the cavity in the cooling circuit. The resonant frequency was tracked using a simple phase locked loop.

The scaling constant, α, was measured for the scaling law: $\Delta f = \alpha\Delta T$, where Δf and ΔT are the change in resonant frequency and the change in water temperature respectively (see Fig.3). At $91.0 \pm 2.0\ ^0$F, α was measured to be 8.0 kHz/K. An estimation of α, by assuming uniform expansion of cavity volume and using the linear expansion coefficient for copper, is 5.4 kHz/K. It is believed that the discrepancy is due to non-uniform cavity expansion and the presence of stainless steel plates mounted on the two end-walls of the cavity. Further study will be carried out to understand this discrepancy.

The stability of our water system is about $\pm0.5^0$F. Thus, the fluctuation in resonant frequency due to coolant temperature variation is controlled to be within ±2.2 kHz.

RF Power Dependence of Resonant Frequency

The designed nominal power is different for each RT-CH cavity. The highest one can go as high as 40 kW. This suggests an average power consumption of 400 W with a 1% duty factor. This will result in a significant heat load on the cavity which would cause a shift in its resonant frequency. The behavior of the cavity under high power should be studied to assure normal operation. The resonant frequency sensitivity to RF power is measured for RT-CH #2 (see Fig. 4).

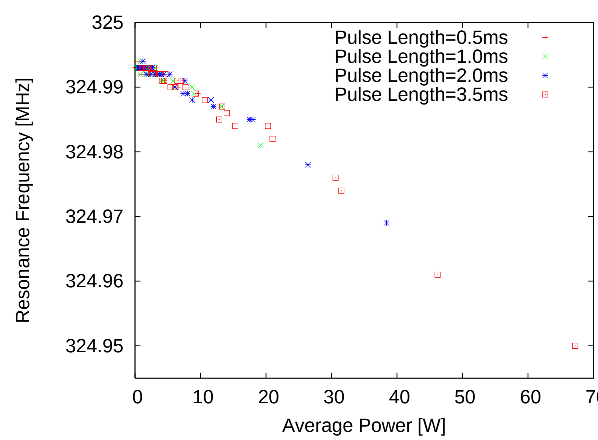

Figure 4: Cavity resonant response to RF power.

The resonant frequency of the cavity was measured for average RF power ranging from zero to about 68 W. The average RF power was controlled by adjusting the repetition rate (0.2 to 2.0 Hz), the pulse width (0.1 to 3.5 ms), and the nominal peak power (1.2 to 9.6 kW). The shift in the resonant frequency was measured to be about 43 kHz and responded linearly to the change in average power. The corresponding sensitivity is about 632 Hz/W. Notice that the change in resonant frequency does not depend upon the way in which the average power is being adjusted. Similar studies will be carried out on the rest of the RT-CH cavities.

The dynamical response of the resonant frequency to a jump in average RF power was also studied (see Fig.5). The repetition rate was set at 0.5 Hz and the nominal peak power at 8.0 kW while the pulse width was set to jump from 0.5 to 3.5 msec. This is equivalent to an average power jump from 2 to 14 Watts. The time constant of the response of the frequency was measured to be 73 sec.

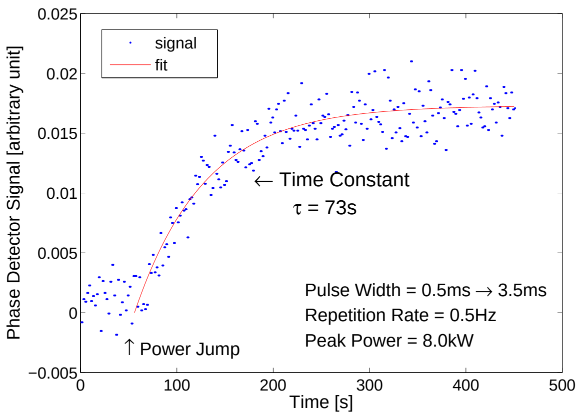

Figure 5: Dynamic measurement of cavity resonant response to RF power.

Plunger Tuner Test

A pair of identical motor-driven tuners was installed on RT-CH #1. The full stroke, or the plunger active length, is about 42 mm or 106,000 motor steps. The resonant frequency of the cavity was measured by a network analyzer. With identical movement for both tuners, the tuning range was measured to be 1290.6 kHz. Resonant frequency responded linearly to the tuner position. The corresponding sensitivity is 30.7 kHz/mm or 12.2 Hz/step (see Fig. 6).

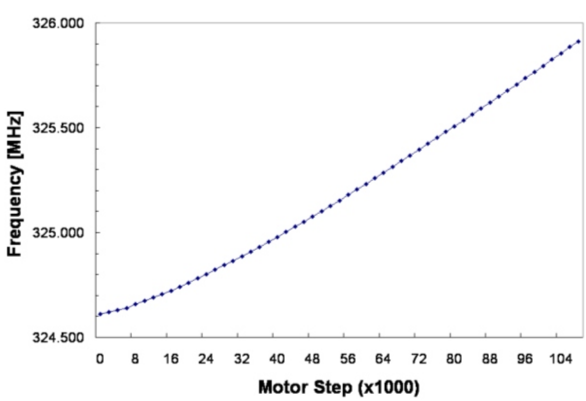

Figure 6: Cavity resonant frequency versus tuner position.

In a design revision the number of tuners is reduced to one and the full stroke of the tuner is cut by a half to 21 mm to improve the tuner's mechanical performance. The new design is sufficient to provide a reasonable tuning range.

RF Power Test with Vector Modulator

Eventually these RT-CH cavities will be powered by a single klystron. To ensure control over the phase and the amplitude of individual cavities, a vector modulator (IQM) is required by each of them. A high power test of the cavity with IQM is performed (see Fig. 7).

By manipulating the drives (yellow and blue) of the IQM, the amplitude (red) of the cavity can be controlled within 13 dB. Detailed discussion on the design and performance of these IQMs can be found in this conference [5].

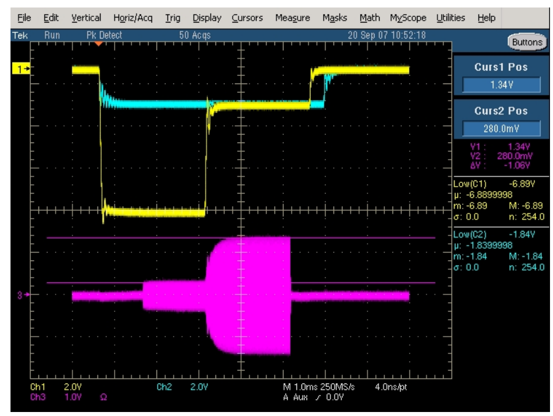

Figure 7. Amplitude control with IQM for a 6 kW 3.5 msec RF pulse. The red trace is cavity RF amplitude; the blue and the yellow are modulator bias currents.

CONCLUSIONS

The first three of the sixteen HINS RT-CH cavities are complete and tested. These cavities have met all of the design requirements. The time needed to condition up to full power for RT-CH #2 is significantly shortened as a result of baking. Cavity sensitivity to coolant temperature, tuner position, RF power and IQM bias has been measured. These results are useful for RF control design and cavity performance improvement effort.

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