RESULTS OF BETA=0.12 QUARTER WAVE RESONATOR FOR RADIOACTIVE BEAMS PRODUCTION AT SPIRAL2 FACILITY

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Abstract

Spiral2 is a French facility which aims at the construction of superconducting linac to deliver proton, deuteron (5 mA, 40 MeV) and Q/A=1/3 (1 mA, 14.5 MeV/u) beams. In this framework, IPN is in charge of the high beta part (beta=0.12). Dedicated Quarter Wave Resonators working at 88MHz require accelerating field of 6.5 MV/m. First prototype has been built and we present here the status of the work performed on it including Q-disease effect, microphonics and cold tuning system.

INTRODUCTION

The Spiral2 facility will be dedicated to radioactive ion beam production and based on a superconducting linear accelerator. The design of this facility has been achieved [1,2] and the superconducting sections will work at 88 MHz.

The linac, optimized for deuteron beams (40 Mev, 5 mA), will be able to deliver stable ions from proton to heavy ions with a charge over mass ratio of 1/6. The injection part is made of two ECR sources and a Radio Frequency Quadrupole to deliver beams with output energy of 0.75 MeV/u. The high energy part is made of two kinds of quarter wave cavities: low beta part (beta=0.07) supplied by CEA Saclay [3,4] and high beta part (beta=0.12) supplied by IPN [5]. The beam final energy is 20 MeV/u for deuterons and 14.5 MeV/u for heavy ions. Radioactive beams will be produced by the ISOL method.

The preliminary work on the beta=0.12 cavityprototype has been achieved and the project is entering in the cryomodules construction phase. In first part of this paper is presented the Q-slope study, including Q-slope disease and effect of the liquid helium tank. In a second part, we present results on the movable plunger based cold tuning system. Then, microphonics effects are shown.

Q-SLOPE STUDY

Experimental setup

For the prototype, it is very important to know the behaviour of the cavity in the accelerator environment and we tend to reproduce similar conditions in a vertical cryostat. First, we have studied the cavity performances without its helium tank by plunging the cavity directly in liquid helium. Then, helium tank has been added and Q-slopes are compared. These results have already been presented in previous papers (see [6] and references therein). Another important effect in the accelerator environment is the cooling down time. It has been shown that a long stay at the temperature range 70-140K is responsible of surface resistance increase, induced by formation of niobium hydride. This phenomenon is well-known and measured at frequencies above several hundreds of MHz [7]. In our case, the cavity frequency is much lower, and only few data on this effect in this frequency range have been published. Because the BCS surface resistance at this frequency is rather low, inducing a high quality factor (10^9-10^{10}), the 100K-effect could dramatically increase the surface resistance. In order to reproduce these conditions, heaters have been placed on the bottom of the cavity and into the stem to warm up from 4.2 K and keep the cavity in the temperature range of 70-90K.

Accurate Q-slope measurements requires critical coupling (beta=1). The vacuum and helium vessel of the vertical bath cryostat have been modified to test cavities equipped with their helium tank. Because of the small cavity frequency bandwidth ($Q_L \approx 8.10^9$, F≈88MHz, $\Delta F \approx 10^{-2}$Hz), Q-slope measurement requires a closed RF loop to follow the cavity frequency. This experimental setup has been already presented in [6].

Effect of the helium tank

The cavity helium tank is made of stainless steel and does not cover the bottom of the cavity. RF losses are very low in this area and thermal calculations showed that heat conduction from the helium tank through niobium is high enough to cool-down the cavity bottom part and the coupling port. Figure 1 shows the Q-slope measurements before and after the helium tank welding.

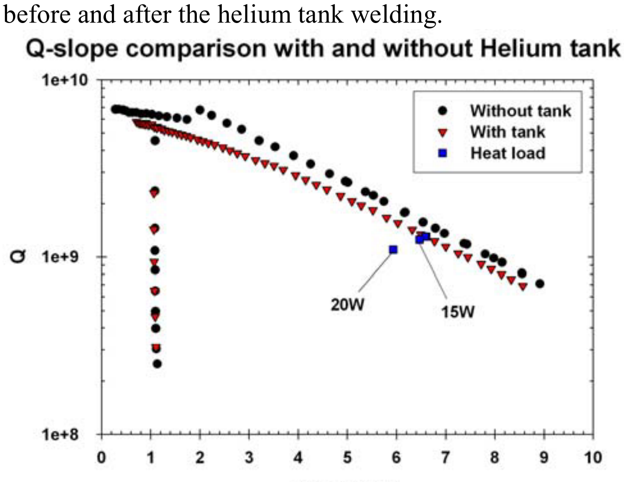

Figure 1: Effect of the Helium tank on the Q-slope

A heater has been added on the coupling port to reproduce the power coupler heat load. The accelerating field is fixed to 6.5 MV/m (requirement) and the thermal power is increased up to 20 Watts. No effects on the Qo curve are observed up to 10 Watts. At 15 Watts, a small Qo degradation is observed. These results show that the cavity does not require an helium tank in the bottom part. Heat conduction through niobium is efficient enough to prevent heating from HF dissipations on cavity and from heat conduction through the power coupler [6].

Q-disease effect (100K)

Because of hydrogen pollution into niobium sheet, the time spent in the temperature range of 70-140K is critical for the cavity performances. Hydrogen precipitates with niobium to form hydrides which have poor superconducting properties. This phenomenon is known for several kinds of cavity [7,8]. Because of the high quality factor of the cavity and the amount of material to cool down, we expect to encounter Q-disease.

The effect of the cool down time can be investigated by warming up the cavity up to 70-90K during several hours. Then, the cavity is cooled down again and Q-slope measurements are performed. This process is repeated to accumulate the effect. Because of the large cavity dimension, we must carefully warm the top and the bottom of cavity at the same temperature to trig the hydride formation in same time everywhere.

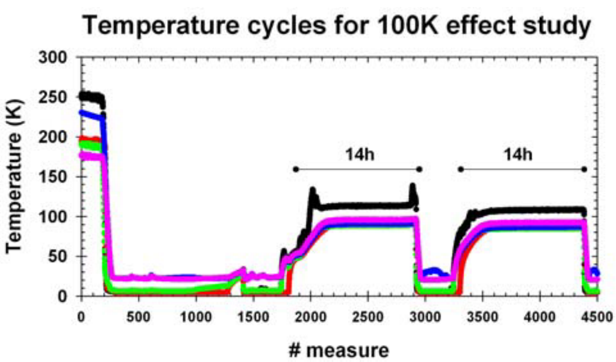

Figure 2: Temperature profile over different part of the cavity during all warm up at 90K and Q measurement

Figure 2 presents the cavity temperature profile over during experiments. The cavity has been subjected to two warming-up cycles of 14h. Q-slope measurements are performed between each cycle.

Surface resistance is calculated from Q-value using the relation $R_s=G/Q_0$ where R_s is the surface resistance, G the geometrical factor and Q_0 the measured quality factor. The surface resistance R_s is given by $R_s=R_{BCS}+R_{res}$. with R_{BCS} the surface resistance given by the BCS theory and Rres the residual surface resistance. Our hypothesis is to assume R_{BCS} constant (R_{BCS}=3.1nOhm) and include the hydrides effect in the residual resistance [8]. One can then deduces the residual resistance for different time spent at 90K versus the accelerating field (figure 3). These results show a linear dependence of the residual resistance increase with the time spent at 90K. The residual resistance increase rate at 1 MV/m is above 0.38 nΩ/h and the Q_0 is degraded by a factor two after 14 hour spent at 90K.

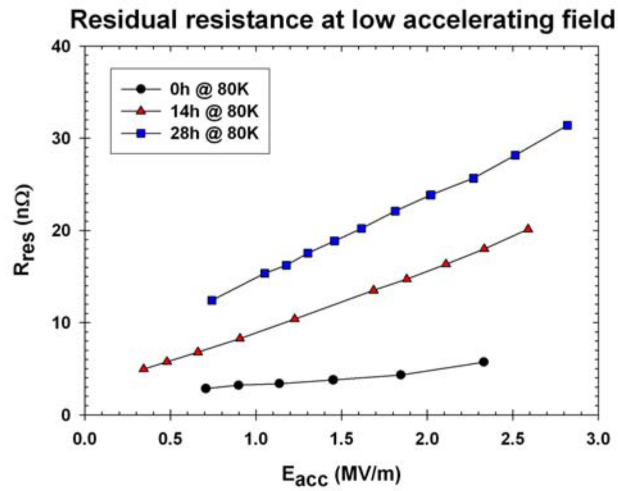

Figure 3: Measured residual resistance

By interpolating these measurement for an accelerating field of 6.5 MV/m, we deduce the evolution of residual resistance versus the time spent at 90K (Figure 4) at the Spiral-2 nominal accelerating field .

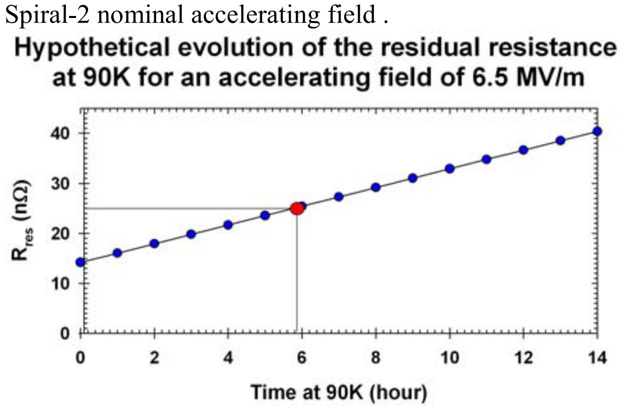

Figure 4: Estimation of residual resistance as a function of the time spent at 90K.

. It leads to an Rs increment rate of 1.85 nΩ/h. To fulfil the Spiral-2 requirements, the residual resistance must be kept under 25 nΩ. This value is reached after only 6 hours of 90 K exposure. Even if it is based on several hypotheses that could be discussed, this analysis has been used to estimate the impact of a slow cavity cool-down on the cavity performances. In these conditions, it appears that a baking could be required.

COLD TUNING SYSTEM

Design of plunger based tuning system

The use of a movable plunger has been chosen to reach enough dynamic and sensitivity on the cavity tuning. A first tuning will be performed with a static plunger to correct the detuning coming from construction tolerances. Results on the effects of static method have been recently published [9].

The plunger is made of niobium and has a 30 mm diameter. It is mounted on the top of the cavity to reach maximum sensitivity. A bellow is placed between the cavity flange and the plunger to allow displacement in liquid helium (see figure 5). The plunger is fixed on the external flange of the helium tank to another bellow. This one is attached to a stainless steel rod which is used to transfer motion from the step motor mounted on the top of the cryostat. This system allows a 5 mm displacement. After preliminary plunger displacement verifications, we have studied the tuning system sensitivity and its effect on Q-slope.

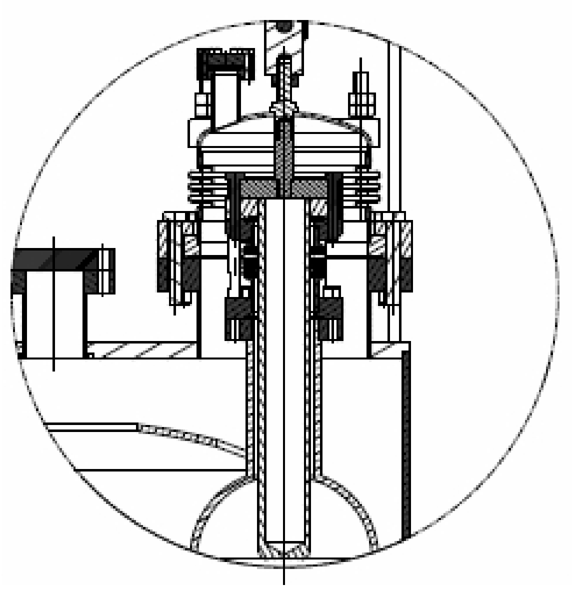

Figure 5: Plunger system inserted in the cavity through the helium tank.

Frequency study

The plunger is moved up and down. the cavity frequency is acquired during the plunger displacement (figure 6).

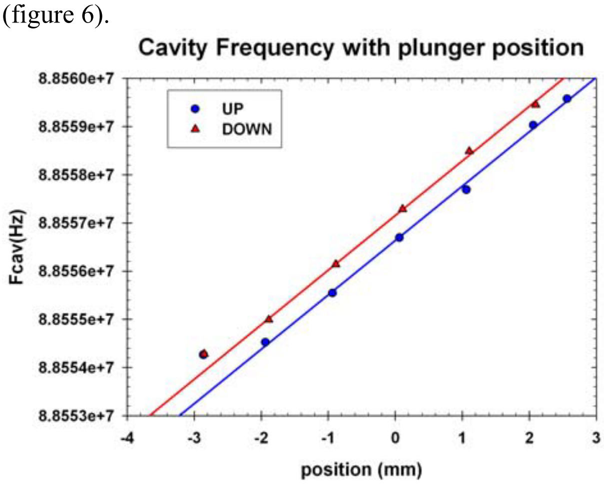

Figure 6: Cavity frequency measurement as a function of the plunger position. Blue dots: upward plunger displacement; Red triangles: downward displacement

The measurements clearly showed an hysteresis of 0.75 mm coming from the motion system. Indeed the displacement is transmitted by a deported rod which has mechanical motion. The sensitivity of the tuning is 1130Hz/mm (1129 Hz/mm by moving up and 1132 Hz/mm by moving down). These values are consistent with those predicted.

Effect on the Q-slope

We have also performed measurement of the Q-slope with the plunger (figure 7). Although the Q-value is high all over the accelerating range, we have reached the maximum accelerating filed of only 6.9 MV/m. This result is disappointing regarding previous measurements with static plunger [9].

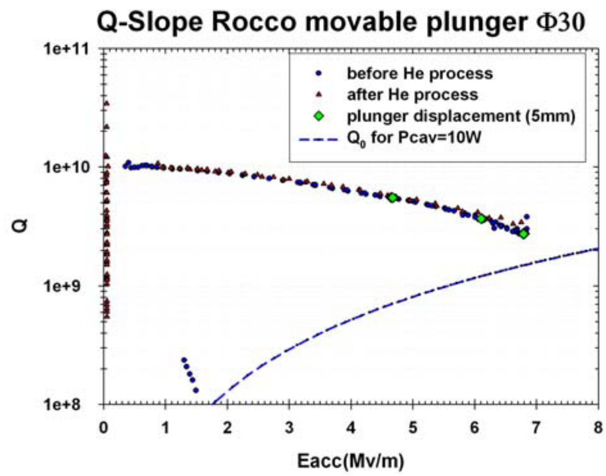

Figure 7: Q-slope with the movable plunger.

However, the cavity has not been prepared in the better condition, only in class 1000 environment instead of class 100 normally. field emission has been encountered from accelerating field of 4 MV/m and we have performed helium processing to clean the cavity. of the processing time was probably not enough (1 hour) but we have decrease the X-ray activity (measured just outside the cryostat) of one order of magnitude (5 mSv to 300µSv). Still, the effect on the Q-slope and maximum accelerating field is rather low. Then we have moved the plunger at the maximum accelerating field and no quench occurred. The plunger position does not affect the Q-value. Although the results on the quality factor are good, the maximum accelerating field has only a small margin compared to the cavity requirement (6.5 MV/m). Presently, we investigate on the possibility of a defect on the plunger or limitation of the energy dissipation in the helium bath through the plunger. Otherwise, we have not observed additional field emission with plunger displacement. Test on the reliability of this tuning system will be performed in the first cryomodule.

MICROPHONICS

Experimental setup

Because of the narrow bandwidth of this kind of cavity in the accelerator environment (above 100 Hz with beam), we must take care of vibrations. Theoretical results have been presented recently [10] and complementary vibration modes measurements are required.

The experimental setup is depending on the cavity bandwidth. For a large bandwidth, one can use an open loop coupled with a mixer and measure the detuning with a lock-in (fig. 8). With this set-up, a large range of detuning measurement is accessible. This is the ambient temperature measurement case where the quality factor is equal to above 5000, giving a bandwidth in the order of magnitude 10^3 Hz. For a narrow bandwidth (<10Hz), the cavity frequency is changing because of pressure fluctuations and other phenomenon. Using a fixed frequency excitation is not adapted because it becomes quickly out of range of the cavity bandwidth and measurements are impossible. This is the case for cold measurement at critical coupling where the cavity bandwidth of the cavity is in the order of magnitude of 10^{-2} Hz. The closed loop is coupled with a cavity resonator monitoring (CRM) which gives a signal proportional to the detuning amplitude. The CRM output is injected into the lock-in.

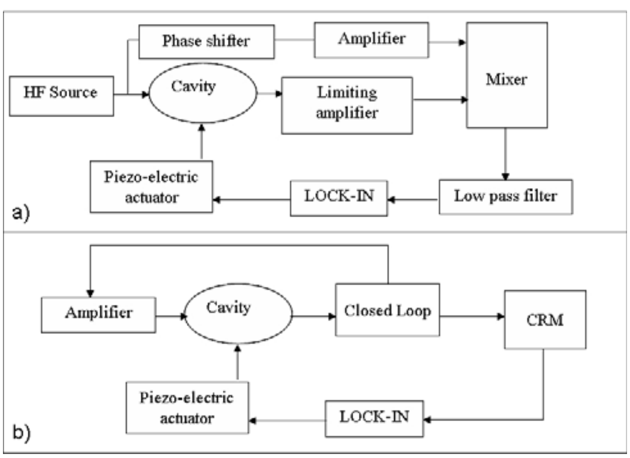

Figure 8: microphonics measurement: a) open loop; b) closed loop

Microphonic measurement with and without excitation

We have performed measurements at the critical coupling. We used the CRM coupled to the closed loop (figure 8b). Measurements with and without excitation have been performed. The excitation was applied by means of a piezo-electric actuator mounted on the top of the tuning system (near step motor, outside the cryostat). Results are presented on figure 9.

The noise spectrum shows a peak around 50 Hz. It seems to be essentially caused by electronic noise according to the excited spectrum and theoretical modes. The integrated spectrum gives a measured frequency distribution width less than 3Hz. This means that the cavity is in a good insulated environment, preventing mechanical vibrations coming from pumping system. The excited spectrum shows several resonance modes. Their quality factors are less than 50. Comparing with mechanical simulation, some differences appear. The main reasons are that the calculations are performed at ambient temperature and for a free cavity. In this experiment, the excited cavity is at liquid helium temperature and the boundary conditions are different (fixation point, movable plunger).

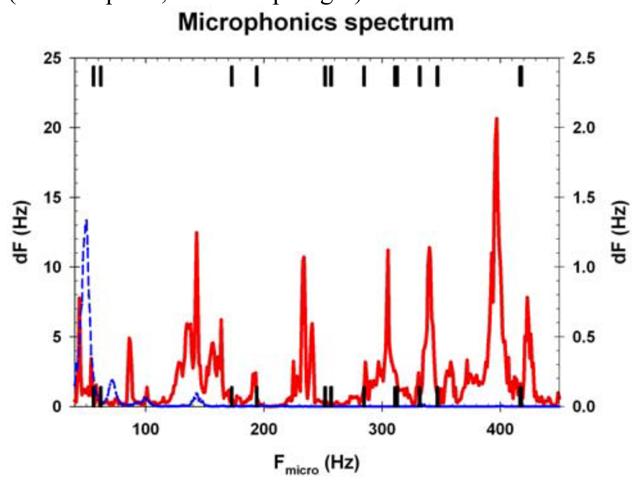

Figure 9: microphonics spectrum with and without excitation. Continuous curve: excited spectrum, scale on left axis; Dashed curve: noise spectrum, scale on right axis. Black dashes: mechanical resonances.

New microphonic measurements will be performed on the cryomodule because the boundary conditions will be different. The pumping system will be also different, especially the localization, using turbo molecular pump generating different mechanical vibrations.

CONCLUSION

Results presented here are really promising and fit with the Spiral2 requirements. Tests on prototype have been achieved and other tests will start soon on the pre-series cavity. The geometry has been slightly modified and optimized to reduce field multipacting. Results have to be confirmed with the test of two cavities in the Spiral2 cryomodule with power coupler provided by LPSC laboratory [12,13].

A new dedicated experimental area is under completion at IPN Orsay to perform these tests and to study the tuning system and power coupler reliability. During these experiments, the cryomodule cooling down time will be measured, specially the time taken to go through the critical temperature range where Q-disease effect might appear. Depending on the results, the cavity baking at 600°C for hydrogen degazing is a process that will be added to the cavity preparation procedure to get rid of the 100 K effect.

Serial production and test of the seven high beta cryomodules will start at the beginning of summer 2008 and will be completed in 2010.

ACKNOWLEDGEMENT

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