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BEAM LOADING WITH THE FIRST REBUNCHER OF SPIRAL2, FIRST MEASUREMENTS

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Abstract

The SPIRAL2 LINAC acceleration start with an RFQ (Radio Frequency Quadrupole). In the MEBT (Medium Energy Beam Transport) Line, the beam passes through rebunchers. The beam intensity is up to 5 mA. We need to take care of the beam loading as the RF (Radio Frequency) power in the cavity can give energy to the ion beam and also the ion beam can give energy to the cavity. This paper presents the effects of the beam on the rebuncher cavity

REBUNCHER CAVITY

Three identical rebunchers (see Figs. 1 and 2) are located in the MEBT Line. Only the first rebuncher is used today on the diagnostic plate to characterize the different beam parameters [1].

A solid-state amplifier is used with a 10 kW maximal output power. Actually, the power at the cavity entrance is 6-8% lower due to the losses in the circulator and RF transport lines. The maximum nominal voltage is 120 kV. The proton nominal value is 38 kV.

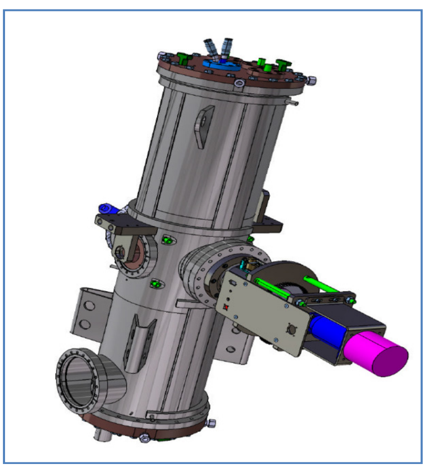

Figure 1: Cavity.

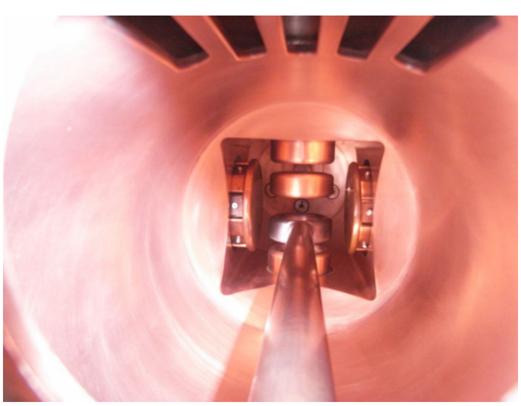

Figure 2: Inside the cavity.

Table 1: Parameters

Parameter	Value	Unit
Design voltage (continuous)	120	kV
Design voltage (50% DC)	190	kV
Beta	0.04	%
TTF	0,38	
Q_L	3335	
Power loss (@120 kV CW)	5.0	kW
Power loss (@190 kV)	12.2	kW
Tuning range	+/-300	kHz/mm
Cavity aperture diameter	60	mm
Gap distances	13 .30 .13	mm
Flange to flange distance	280	mm

RF REGULATION OF THE CAVITY

The RF system is regulated by a general LLRF (Low level radio Frequency) numerical system developed at Saclay. The regulation used in SPIRAL2 is a control feedback loop (see Fig. 3). The frequency choosed for the sample clock is 70.422 MHz (the RF is 88.0525 MHz). The signal reference and the cavity signal are sampled and compared. Then an equation is applied to model the loop filter. The loop filter is a P.I.D. (proportional, integrated, derivated) structure. Actually, we use only the P and I parameters to stabilize the RF voltage. The filtered error is then converted to analog signal and sent to an IQ (In phase and in Quadrature) modulator to correct the error. So, the amplitude and phase compensation cannot be separated.

Others classical systems used are often amplitude and phase separated loops. The goal values for the regulation are : amplitude error < 1% , phase error < 1° for the complete system. It contains a post mortem system which can be used as a precise monitoring system in the ns scale.

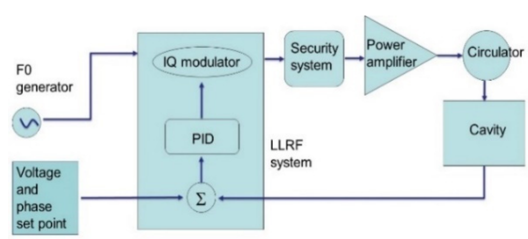

Figure 3: Regulation system.

EXPERIMENTS

The effects of the beam are evaluated when the rebuncher is in open loop regulation and in closed loop. The phase offset between RFQ (reference phase) and rebuncher is tuned from -180 to +180°. We record the phase offset and the voltage offset induced by the beam in both open and close loop regulation. This experience is made for different beam currents.

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For the experiment, the beam is pulsed during 5 ms 'on', with a repetition rate of 300 ms (see Fig. 4). The transition when the beam passes through the rebuncher can be easily observed.

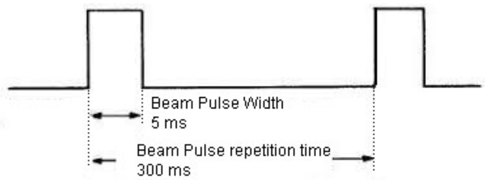

Figure 4: Beam pulsation.

In the following example, the phase timing for the rebuncher is choosed at -60° and the voltage is set to 38 kV

Open Loop

Figures 5 and 6 show the 5 ms beam pulse over a 400 ms observation time for a phase offset of 60°.

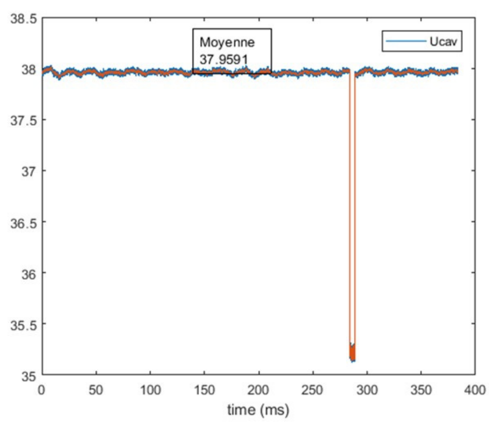

Figure 5: Voltage offset (kV), open loop.

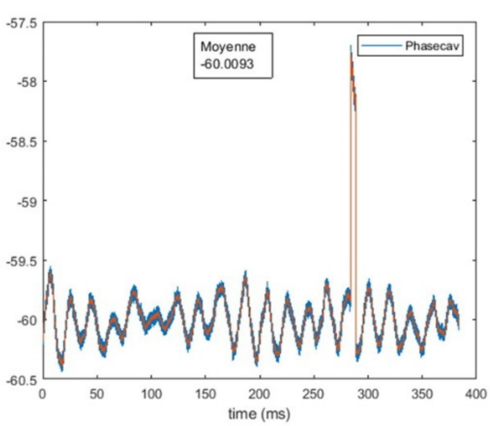

Figure 6: Phase offset (°), open loop.

On these figures, the beam induce a voltage drop of -2.7kV, and a phase increase of +2°.

Closed Loop

Figures 7 and 8 show a temporal zoom of the beam pulse (5 ms) highlighting the beam pulse rise and fall effects.

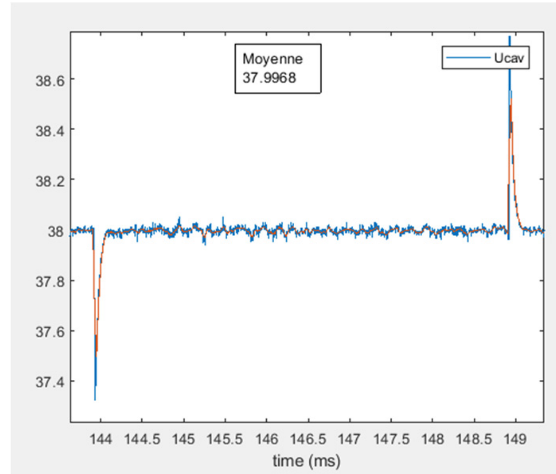

Figure 7: Voltage variation, closed loop.

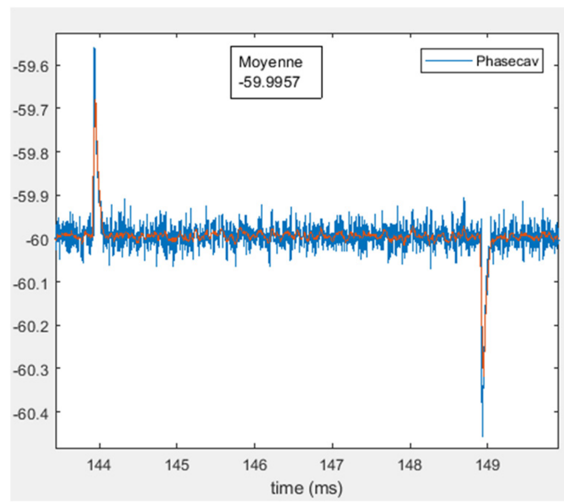

Figure 8: Phase variation, closed loop.

From those figures, the LLRF regulation time is then found to be about 100 µs, a satisfactory value for the LINAC. More important, the remaining voltage error is in this case about +/-1.8%, and far from the 1% acceptable limit when the cavity is phase tuned to the rebuncher mode,

Taking into account the Q_L of the cavity, very little margin should exist to improve the regulation time without introducing instabilities in the amplitude/phase feedback control.

Voltage and Phase Offset with the Rebuncher Phase

Figure 9 shows the measurement for the 2.2 mA beam current. We are varying the RFQ/ rebuncher phase from -180° to +180°. The rebuncher is set in open loop regulation to see the beam influence. The curves indicate the voltage and phase offset induced by the beam during the pulse. The maximum (in absolute value) voltage influence is when the phase offset is zero and the maximum phase influence is when the voltage offset is zero.

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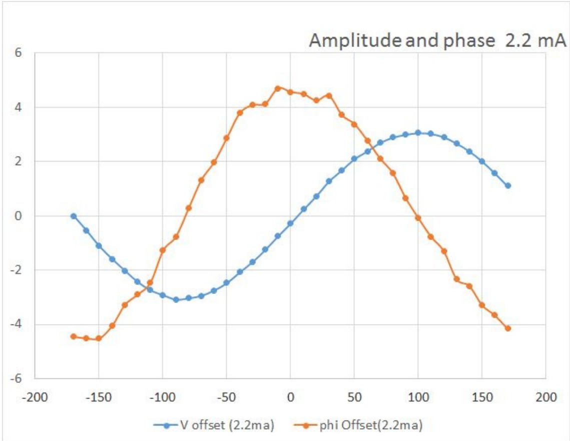

Figure 9: Voltage and phase variations, with the phase setting point of the rebuncher.

Measurements of the Voltage and Phase Offsets with Different Beam Currents

We can observe the proportionality of the voltage and phase deviation (in volts and degrees, see Figs. 10 and 11) with the beam intensity versus the tuning phase of the rebuncher. More the beam intensity is high more the voltage is high but the maximum influence depends on the phase set point. It's the same for the phase.

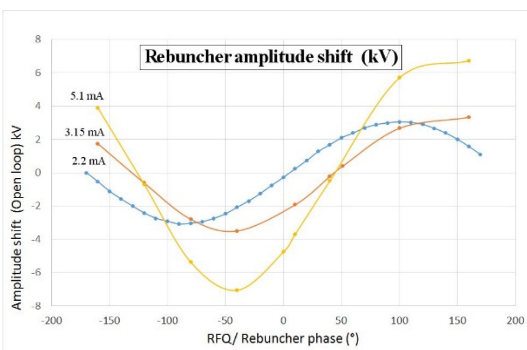

Figure 10: Voltage variations, with the phase setting point of the rebuncher, open loop.

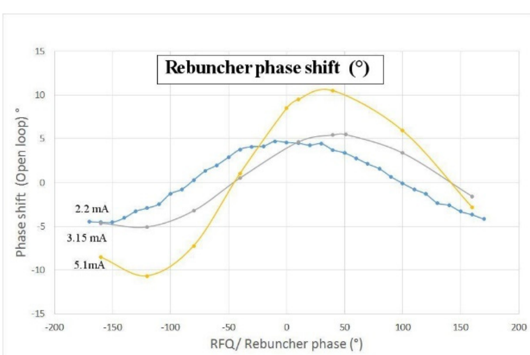

Figure 11: Phase variations, with the phase setting point of the rebuncher, open loop.

SIMULATIONS MATLAB

Many studies have been made on this subject in many laboratories like CEA-Saclay [2] and CERN [3]. The RLC model circuit (Resistance Inductance and Capacitance) of a cavity with a RF generator and Current beam generator describes the system.

The differential equation can be explicated into two differential equations with real and imaginary parts, see Eqs. (1-3):

$$\frac{d^2V}{dt2} + \frac{1}{R_LC}\frac{dV}{dt} + \frac{1}{LC}V(t) = \frac{1}{C}\frac{dI}{dt} \quad (1)$$

$$\frac{dV_{re}}{dt} = -\frac{\omega_0}{2Q_L}V_{re} + (\omega - \omega_0)V_{im} + R_L\frac{\omega_0}{2Q_L}I_{re} \quad (2)$$

$$\frac{dV_{im}}{dt} = -\frac{\omega_0}{2Q_L}V_{im} - (\omega - \omega_0)V_{re} + R_L\frac{\omega_0}{2Q_L}I_{im} \quad (3)$$

Using our rebuncher description we can simulate the beam effect on the cavity RF parameters. As the rebuncher is not a superconducting cavity, we are always in the cavity band pass (Fig. 12).

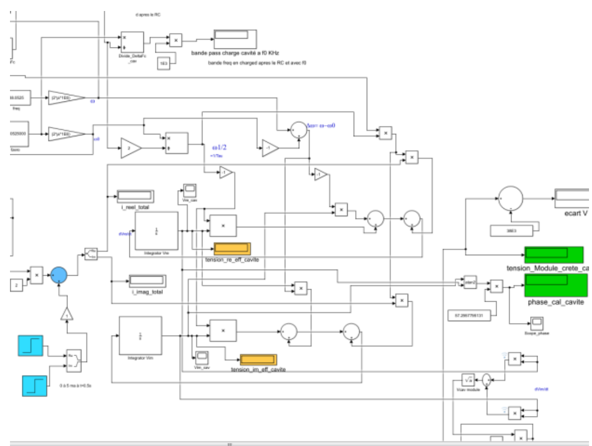

Figure 12: Extract of Matlab Simulink simulation diagram.

Comparing the curves of Fig. 9 (measurement) and Fig. 13 (simulation): The offset seen in voltage is about 5 to 6 kV at his maximum both in measures and simulation and the offset in phase is between 3.8° to 5° at his maximum point.

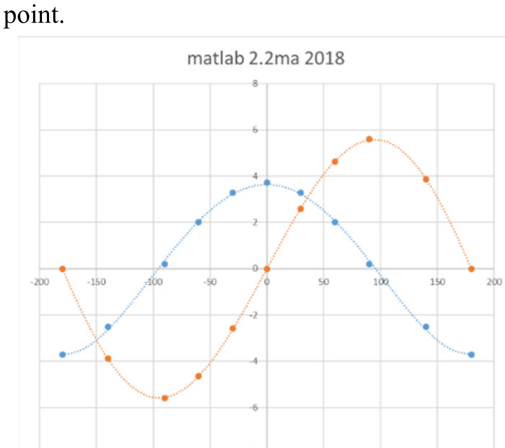

Figure 13: Matlab results.

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CONCLUSION

The comparison between experiments and Matlab calculation are quite in accordance. More precise parameters like the shunt resistance should give better results for the simulation model and find the measured values. An interesting and long work to compare model and measurement is to come.

The next steps are to measure and to take into accounts the effects of the beam, on our cryo-cavities, with control loops, detuning effects and so on, in the aim to tune the beam, up to the experimental areas. The behavior of the phase and voltage in the cavities with the beam will help strongly to find the best solution to apply the right regulation at the good instant, and so to tune the beam in all situations to the end of the Linac.

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