RF SYSTEM FOR THE SUPERCONDUCTING LINAC DOWNSTREAM FROM DEINOS INJECTOR

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Abstract

The DEINOS injector will be followed by an accelerator consisting of one LEP-like cryomodule including four 4-cell superconducting cavities. Each of these cavities will be fed by a solid-state amplifier delivering 20 kW in CW operation at 352 MHz. We will use the technology developed by the "Synchrotron SOLEIL" RF team, consisting of merging the power of numerous independent 330 W modules. The design of the low level RF system will be based on our experience with the ELSA accelerator.

INTRODUCTION

Deinos is a 2.5-MV injector prototype for an accelerator dedicated to flash X-ray radiography. The accelerating section consists of one LEP2 croyomodule hosting four 4-cell superconducting 352-MHz cavities (fig. 1). As a majority of LEP2 cavities eventually reached a gradient of 7.5 MV/m, well above the 5 MV/m design value [1], we choose this gradient for our accelerator, leading to a final energy of 51 MeV. During the 55-ps electron pulse, each of the 20 RF buckets is filled by a 100-nC bunch. Beam dynamics of such an accelerator was studied By N.Pichoff with PARMELA and PARTRAN [2]. It was shown that beam size on target depends directly on energy spread.

With such a short electron pulse, the stored energy drop cannot be compensated by extra RF power during the pulse. To guarantee an accurate beam energy, we must then: 1) minimize the energy instantaneous drop due to beam loading, 2) accurately control cavity voltages prior beam arrival.

Whereas the first point concerns fundamental choices in linac and cavity design, the second point only deals with RF control *without beam loading*. So, from an RF control point of view, our cavities are considered as beam free.

STORED ENERGY CONSIDERATIONS

Minimizing the beam energy spread is critical in our machine, and we will show it has a consequence on the choice of the RF frequency.

In the linac, a part ΔW of the total stored energy W is transferred to the beam: $\Delta W=-qU$, q being the total beam charge, U being the total accelerating voltage. As $W=U^2/(2\omega R/Q)$, the stored energy drop causes a voltage decrease ΔU such as: $\Delta U/U= 0.5\ \Delta W/W$.

The total linac R/Q is proportional to the number of cell n: $R/Q=n(r/Q)$, where r/Q is for a single cell. This number of cell is linked to the accelerating gradient E_{acc}, and to the cell length (assumed to be half of a wavelength), leading to: $U=E\times n\times c/2f$. Combining these equations leads to:

$$\frac{\Delta U}{U}=\frac{1}{\pi c}q(r/Q)\frac{\omega^2}{E_{acc}}\ .$$

To our knowledge, the highest proven value of E_{acc}/ω^2 in operational superconducting β=1 cavities is attained by LEP2 units. This is the reason of the choice of 352 MHz for RF frequency.

Figure 1: A LEP2 Nb-Cu cavity.

REQUIRED RF POWER

With a hypothetic beam such as no power is reflected back to the generator, the nominal RF power required per 4-cell cavity would be : $U_{cav}^2/(2(4\ r/Q)Q_{ext})$, where U_{cav} is the voltage in a cavity. Actually, without beam, all the power is reflected: the cavity behaves as an open circuit terminator at the end of the line. Then, for a given power, the voltage gains a 2-folding factor. So, P_{req}= $U_{cav}^2/(4\times 2(4\ r/Q)Q_{ext})$. From cavity characteristics listed in table 1, and with a 7.5 MV/m gradient, we get: U_{cav}=12.75 MV and P_{req} =44 kW.

Table 1: Characteristics of LEP2 cavities [3]

Frequency	352.2 MHz
Fast tunability range	1.6 kHz
Slow tunability range	50 kHz
Number of cell	4
Effective length	10.7 m (=4λ/2)
r/Q (circuit)	58 Ω per cell
Effective length	1.7 m
Q_0 (low field)	6.4×10^9
Qext	2×10^6

Since almost all this power is actually reflected back to the amplifier, it is attractive to re-employ this unused power by reflecting it again toward the cavity by a local mismatch. Setting up such a resonance in the feeding line permits to lower the needed power from the amplifier. Actually, this is a possible technique to enhance the external Q seen from the amplifier without any coupler modification

From a field control point of view, we have two advantages (compared to LEP conditions): 1) cavities are considered without beam, 2) each cavity field can be controlled individually, as it will be fed by its own amplifier (see further). Considering these advantages, Michel Luong (from CEA/Saclay) studied the consequence of a Q_{ext} enhancement on the cavity field stability. He showed that if the cavity bandwidth is reduced by a factor of 3, the associated phase error would only raise from 0.05° to 0.5°, which is still acceptable for beam dynamics. In that case, the Q_{ext} grows from 2×10^6 to 6×10^6 and, the nominal RF power drops from 45 kW to 15 kW per cavity.

Practically, we showed that this Q_{ext} enhancement can be obtained by a TOS=3 (ie, $|\rho|=0.5$) local mismatch in the waveguide. In a first CST-MWS simulation with two matched end ports, we dimensioned an obstacle in the waveguide that generates the wanted mismatch. In a second simulation with the same obstacle (fig. 2), a metallic end-wall simulates the total reflection presented by the cavity. The position of the obstacle is set such that the part of waveguide between obstacle and cavity shows a resonance at 352 MHz. As expected, the amplitude enhancement factor apart from the obstacle is $3^{0.5}= 1.73$.

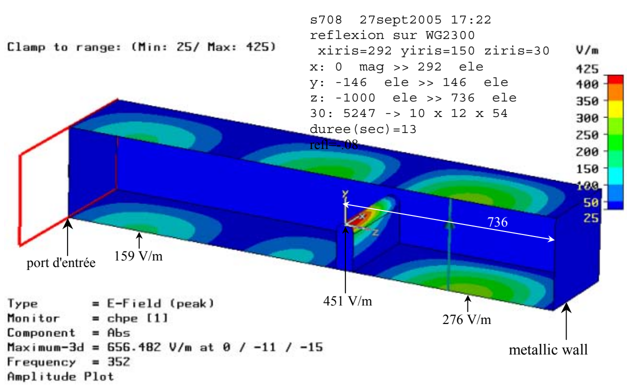

Figure 2: Obstacle in waveguide for3-fold Q_{ext} expansion.

POWER AMPLIFIERS

The technology of solid-state 352-MHz power amplifiers developed at Synchrotron- Soleil is now mature [4] and very well adapted to our purpose.

The power of many 330-W modules (fig. 3) are merged in multi-way combiners. Each module is fed at low voltage though an individual 300V-28V DC-DC converter. Versus vacuum tube, this transistor technology has the following advantages :

- installed power can be adjusted to needs
- modularity insure an easy and low-cost maintenance
- tolerance of single module failure
- no high voltage (higher security)
- short turn on/off delays

In our accelerator, the nominal RF power is 15 kW per cavity. With a 30% margin for losses and regulation, we need a 20 kW amplifiers. A structure equivalent to half of the booster amplifier of Soleil will be taken (fig. 4).

A first 2.5 kW prototype amplifier is currently under tests (fig. 5).

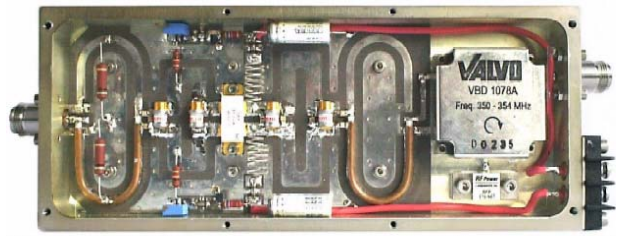

Figure 3: RF module of Soleil amplifier.

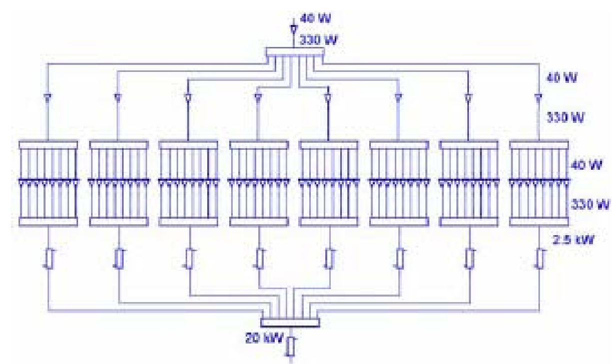

Figure 4: Structure of a 20 kW amplifier hosting 73 modules.

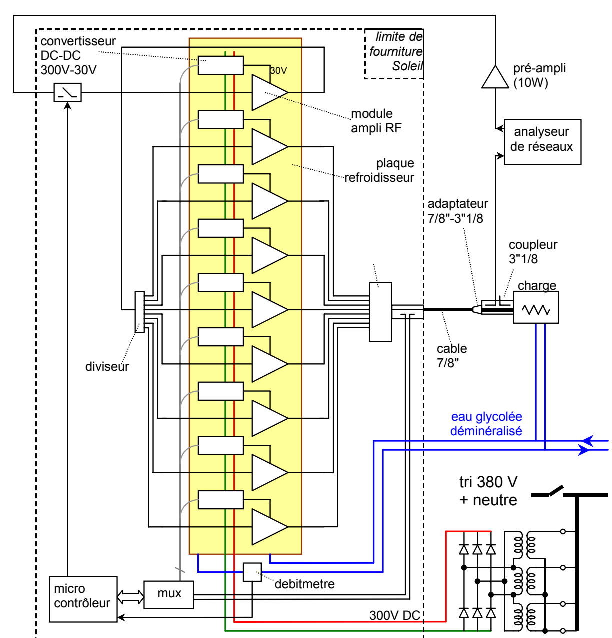

Figure 5: 2.5 kW amplifier currently under tests.

RF CONTROL

Each cavity will be fed and controlled individually. The RF control system is inspired from the one in ELSA machine. The frequency tuning system will use LEP2 one combining magnetostrictive and thermal expansion Ni tubes. Like in ELSA machine [5], phase and amplitude will be regulated by two loops: a fast analog RF loop working at the RF frequency, and a slow digital loop monitored by a personal computer. The digital loop will be based on an analog decomposition of the RF signal in I/Q components. In the computer, subroutines will transform I/Q components into Ampl/Ph ones.

The program will also host routines for automatic measurement and adjustment of the analog RF loop.

ACKNOWLEDGEMENTS

The author thanks Michel Luong from CEA/Saclay for field stability studies. The author is grateful to Patrick Marchand, Robert Lopez, Ti Ruan and all the RF team of Synchrotron- Soleil for furnishing the prototype amplifier.

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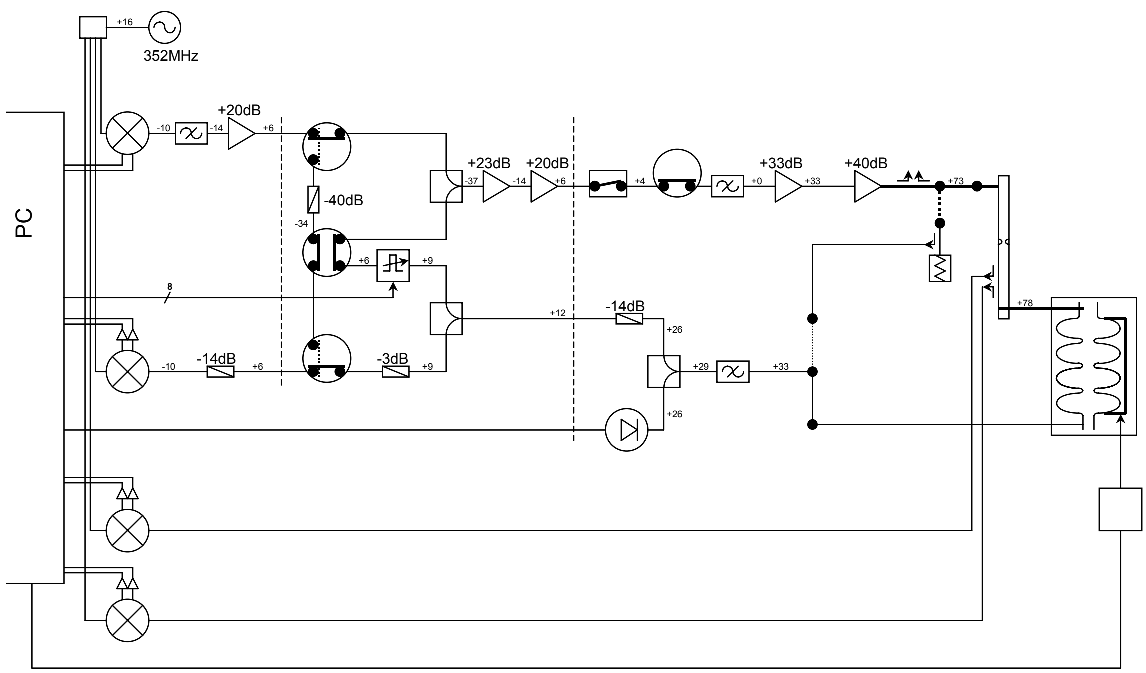

Figure 6: RF control scheme for each cavity.