THE SUPER-3HC PROJECT: AN IDLE SUPERCONDUCTING HARMONIC CAVITY FOR BUNCH LENGTH MANIPULATION

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Abstract

In both ELETTRA and Swiss Light Source (SLS) it is planned to implement a 3rd harmonic (1.5 GHz) RF system in order to lengthen the bunches and consequently improve the beam lifetime. Since their boundary conditions were rather similar, the two laboratories decided to search for a common approach. The chosen solution is the use of an idle superconducting (sc) system based on a "scaling to 1.5 GHz" of the 350 MHz cavity developed for the SOLEIL project. This new development is carried out in the framework of the so-called *SUPER-3HC Project*, a collaboration between CEA-DAPNIA Saclay, Paul Scherrer Institut (PSI) and Sincrotrone Trieste.

1 INTRODUCTION

The main challenge of the new generation of Synchrotron Light Sources is the increase of the radiation brightness, principally through the reduction of the electron beam dimensions (emittance). Unfortunately, the associated enhancement of the bunch charge density results in a significant degradation of the electron beam lifetime (Touschek scattering).

The use of a 3rd harmonic system for lengthening the bunches is widely regarded as the most efficient means of improving the beam lifetime without affecting the energy acceptance. Since it was planned to implement such a system in both ELETTRA and SLS storage rings with similar requirements, the two laboratories decided to search for a common solution. Among the possible variants which were investigated [1,2], the most attractive is an idle sc system based on the SOLEIL two-cell-cavity design [3], "scaled to 1.5 GHz". Following this approach, the HOM are strongly damped by means of loop couplers, located on the tube between the two single cell cavities.

In October 1999, Sincrotrone Trieste, PSI and CEA-DAPNIA Saclay concluded a collaboration agreement, the so-called SUPER-3HC Project, with as objective the design and production of two complete cryomodules, one for ELETTRA and one for SLS. The main features of this system as well as the project status are described here.

2 GENERAL PRINCIPLE

2.1 Beam induced voltage in an idle sc cavity

The beam induced voltage and power loss in an idle cavity - when excited sufficiently far from resonance ($\delta f \gg f_r / Q$) - are given by [2]:

$$V = I_b (R/Q) f_r / \delta f \quad \text{and} \quad P_b = V^2 / (2 R), \quad (1)$$

where R, Q, f_r, are the cavity shunt impedance, quality factor, resonant frequency and $\delta f = h f_o - f_r$, the detuning; h, f_o, I_b, are the harmonic number, the revolution frequency and the beam current, respectively.

A sc cavity with its very high Q is the ideal component for making use of the induced voltage while keeping the beam energy losses at negligible level. Assuming a two cavities assembly with a typical R/Q value of 90 Ω and a beam current of 0.4 A, one finds that a voltage of 0.8 MV is induced at 1.5 GHz when the cavities are detuned by 68 kHz. This amount of detuning which corresponds to several thousands of the sc cavity bandwidth well fulfills the required condition, $\delta f \gg f_r / Q$ and it remains small as compared to the revolution frequency ($f_o \approx 1$ MHz). The induced voltage could be easily maintained even at much lower current by controlling the detuning, still within the previous limits. The beam power lost into the fundamental mode, equal to the wall dissipation, is negligible as compared to the radiation losses per turn.

During the injection, the RF voltage in the sc cavity builds up with the current and the induced transients should always remain quite tolerable. Note that, during the injection, the detuning of the sc cavity is a "free" parameter that can be set "at will".

In the storage regime the RF voltage of the sc cavity is controllable in closed loop via its frequency tuning system. Leaving a gap T_g of empty RF buckets in the electron bunch train is the usual method of ion clearing. The induced modulation of the cavity RF voltage, in return, will produce a phase modulation through the bunch train. One finds from (1) that the maximum amplitude of this phase modulation, $\Delta\phi_m = 2 \pi \delta f T_g$ [4], is about 2° at 1.5 GHz for a typical gap $T_g f_0$ of 10%, R/Q = 90 Ω and V = 0.8 MV. Such a bunch phase spread should not be an issue, on the contrary it should contribute to Landau damping.

2.2 Bunch lengthening

Fig. 1 shows the results obtained when combining the idle 3rd harmonic sc cavity described before with the main 500 MHz nc system, in the SLS case ($V_{nc} = 2.6$ MV). The RF voltages (nc, sc and nc+sc), as well as the corresponding computed RF buckets and bunch profiles are plotted versus phase. With the beam induced voltage of 0.8 MV at 1.5 GHz ($V_{sc} \approx V_{nc} / 3$), a quasi zero slope is obtained over the phase domain covered by the bunch. One finds that the bunches are then lengthened by a factor of about four ($\sigma_z \approx 4 \sigma_{zo} \approx 15$ mm) while the energy

acceptance is nearly unaffected as compared to the single nc system. Consequently, the Touschek lifetime should be also improved by a factor of about four.

Quite similar results are obtained in the ELETTRA case ($V_{nc} = 1.8$ MV and $V_{sc} \approx 0.6$ MV).
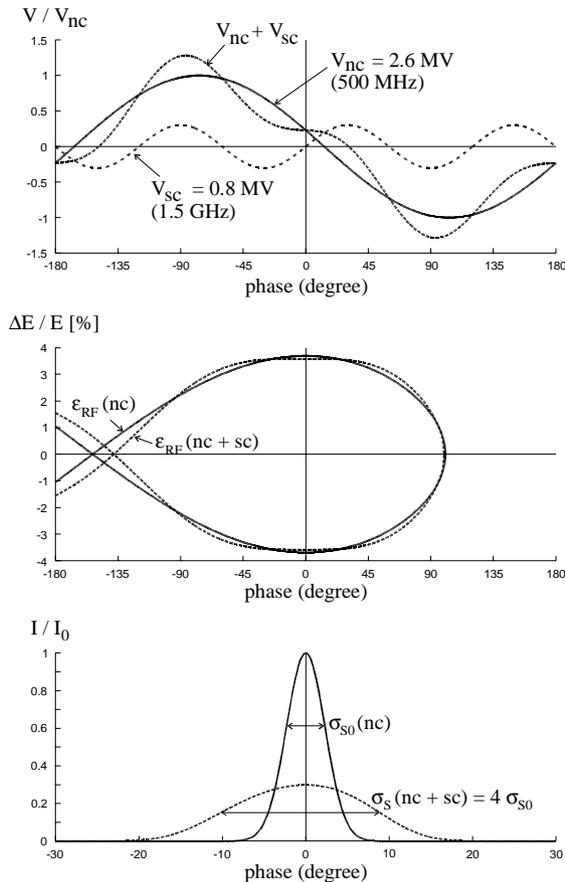

Figure 1: Normalized RF voltages (nc, sc, nc+sc) vs phase, RF buckets and bunch profiles (nc, nc+sc) for $V_{nc} = 2.6$ MV, $V_{sc} = 0.8$ MV and $f_{sc} = 3.f_{nc} = 1.5$ GHz.

Concerning the Robinson stability, the harmonic sc cavity is detuned such that it contributes to anti-damping . The computation of the oscillation growth (or damping) rates [5] for the global (nc + sc) system showed that the stability condition is largely fulfilled with full stored beam current since the sc cavity is then detuned far from the first satellites of the synchrotron frequency. If one wants to maintain the same voltage at reduced beam current, instabilities could theoretically occur (~ a few 10 mA) when exciting a synchrotron frequency satellite exactly in resonance. But this is easily avoidable: changing the frequency of the sc cavity - which naturally has an extremely narrow bandwidth - by a fraction of a kHz should be sufficient to re-establish stable conditions without affecting too much the operating parameters.

Another benefit of the bunch lengthening is that the resulting decrease in peak current should raise the threshold for single bunch instabilities. Moreover, one can expect a significant amount of Landau damping - due

to the non-linearity of the RF waveform - which should help in fighting the coupled bunch instabilities. Note also that the harmonic cavity could easily be detuned in the other direction, shortening the bunches by a factor of about 1.5, if wished.

3 CRYOMODULE DESIGN

3.1 Cavity Design

The SOLEIL RF cavity consists of two-cells connected by a tube whose diameter allows all modes, but the fundamental one, to propagate. Loop couplers at optimum locations on the connection tube couple out the HOMs to external loads. In fig. 2 half SUPER-3HC cavity profile is shown; it is the result of the scaling to 1.5 GHz of the SOLEIL cavity, with few additional optimisations [6].
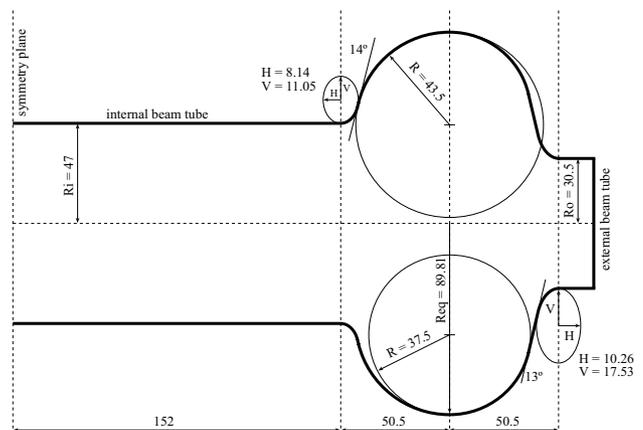

Figure 2: SUPER-3HC cavity.

The diameter of the internal tube connecting the two cells has simply been scaled to 94 mm, its length has been adjusted at 304 mm to gain a factor 10 in the dipole mode damping. The coupler locations are computed with URMEL for all the HOMs whose frequency is below the cut-off frequency of the external cavity beam tubes. Optimum HOM coupler location has been found at 124.7 mm from the cell for longitudinal modes ($H\phi$ coupling) and at 51.8 mm for transverse modes (Hz coupling). With one coupler for each cell and HOM-family (total of 4 couplers), the impedances are damped to 4 kΩ (longitudinal) and to 250 kΩ/m (transverse). For a stored beam current of 400 mA, these values are close to the coupled bunch instability thresholds for SLS (8 kΩ and 250 kΩ/m respectively) and slightly above for ELETTRA (2.6 kΩ and 100 kΩ/m). Thus in the design of the copper model the number of HOM couplers has been doubled, leading to a total of eight. Their actual number will be chosen after the measurements on the model, taking into account the contribution of Landau damping and also that coupled bunch feedbacks will be implemented in both machines. The geometry of the external beam tubes and the shape of the tapers determine the total number of modes trapped in the structure. Considering the different

constraints of ELETTRA and SLS vacuum chamber, the diameter of the external tube has been fixed to 61 mm (direct scaling from SOLEIL).

The calculated fundamental mode R/Q is 44.2 Ohm for each cell of the SUPER-3HC cavity.

3.2 Cryomodule Design

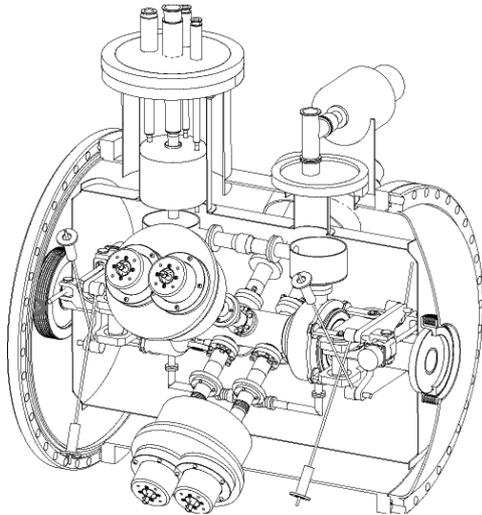A sketch of the cryomodule is shown in fig. 3 [7].

Figure 3: Schematic view of the cryomodule.

The preliminary study of the cryomodule was done in the most complicated case, assuming eight HOM couplers, even if in the final version the actual number could be four. Therefore the internal tube is equipped with ten ports, including two input coupler ports for RF characterisation of the cavities; moreover they could be used to convert the operation mode of the cavity from idle to active. Each cavity has separate tuning system and Helium tank; a He gas cooled shield provides thermal insulation to the cavities. The diameter of the cryomodule is 900 mm and its overall flange to flange length has been kept as short as possible, that is 1.1 m. The curvature of the lateral flange of the cryomodule will be reversed in the final design, to gain space in the tuning system region.

The choice of the cavity material is still open between sputtered Nb/Cu and bulk Nb. For this application the latter could make manufacturing easier.

The tuning system is an adapted version of the SOLEIL one and will operate at cryogenic temperature, under vacuum. The tuning range is anticipated to be about ±600 kHz, sufficient for both SLS and ELETTRA needs.

3.3 Cryogenic considerations

The cavity will operate at 4.5 K. The expected quality factor is $2 \cdot 10^8$, at 5.0 MV/m of accelerating field per cell. For SLS, with 0.8 MV of total accelerating voltage, the RF losses in the cavity attain to about 18 W (for Elettra 10 W with 0.6 MV). 5 W of additional static losses are

expected. HOM losses are being evaluated in order to complete the data for the refrigerator specifications.

For the cryogenic system, a He refrigerator with two turboexpanders and a screw compressor was selected in order to minimise the vibration level. The refrigerator is operated in a mixed liquefier/refrigerator mode in order to cope with the additional load of the warm (300 K) He return from the cryomodule.

3.4 Machine interface and vacuum system

A preliminary analysis of the cryomodule interface to the storage ring and of the possible vacuum system layout has been performed for Elettra. The vacuum layout will be similar to that used for the LEP cavities [8]. Tapers, gate valves and bellows will be installed on both sides of the cryomodule, while a T-junction will be installed on the upstream side, with connections for measuring gauges, pre-vacuum and UHV pumping. The T-junction will host also the synchrotron radiation mask. The needed space becomes then about 2.2 m. Two ionic pumps, 150 lit/sec, will be installed at both sides after the gate valves. This layout should be suitable to keep at a tolerable level the cavity surface pollution from the rest of the machine. Warming up cycles to recover the cavity surface will be done twice a year.

A similar layout will be adopted for the SLS.

4 CONCLUSION AND OUTLOOK

The first phase of the SUPER-3HC project has come to its conclusion with the preliminary design of the cryomodule. The RF characterisation of the cavity copper model, to determine the value of the damped HOM impedances, is presently undergoing at Saclay. The second phase, with the construction of two cryomodules, one for ELETTRA and one for SLS, will eventually start this summer, after a final cost evaluation. Installation of the cavities in both storage rings is planned for spring 2002.

REFERENCES

[1] M.Svandrlik et al., "Design of a 3rd Harmonic SC cavity for bunch lengthening in ELETTRA", EPAC'98, Stockholm, June 1998, p. 1879.

[2] P.Marchand, "Possible upgrading of the SLS RF System for improving the beam lifetime", PAC'99, New York, March 1999, p. 989.

[3] A.Mosnier et al., "Design of a heavily damped SC cavity for SOLEIL", PAC'97, Vancouver, p. 1709.

[4] D.Boussard, "RF Power requirements for a high intensity Proton Collider", PAC '91, San Francisco.

[5] P.Marchand, Note SLS-TME-TA 1998-0012.

[6] DSM/DAPNIA/SEA technical note, "Optimisation of the SUPER-3HC RF structure", Saclay SC-99-01.

[7] DSM/DAPNIA/SEA technical note, "Mechanical pre-study of the SUPER-3HC cryomodule", Saclay 12/99.

[8] H.Preis, CERN-SL Division, private communication