HOM DAMPING IN SOLEIL SUPERCONDUCTING CAVITY

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Abstract

Coupled bunch instabilities are one of the primary performance limitations in high intensity storage rings. For the SOLEIL Light Source, it was decided to develop a two-cavity superconducting system, able to provide the necessary beam power and RF voltage, while strongly damping the parasitic modes by means of two pairs (longitudinal and transverse) of HOM couplers. The overall cavity and coupler arrangement was designed by means of frequency and time domain codes and the final optimization was achieved through low power measurements on copper prototypes.

1 INTRODUCTION

The RF system for the 2.5 GeV storage ring of SOLEIL light source, developed within the framework of collaboration with CERN and ESRF laboratories, consists of a pair of single-cell superconducting 352 MHz cavities linked through a large beam pipe. With such a design, the coupling is very weak for the fundamental mode but very strong for the high order modes (Fig. 1).

The order of magnitude of the required dampings of the longitudinal and transverse HOMs is given by the well-known formulae (assuming short bunches and coincidence of HOM frequency with one single excitation spectral line) :

$$f_r R_s < \frac{2\, Q_s\; E/e}{\alpha\, \tau_s\, I_0} \quad ; \quad f_0 R_\perp < \frac{2\; E/e}{\beta_\perp \tau_\perp I_0}$$

with I_0 the beam current, E the energy, Q_s the synchrotron tune, α the momentum compaction, $\beta_\perp$ the beta function at the cavity location, τ_s and $\tau_\perp$ the longitudinal and transverse damping times, f_r and f_0 the HOM resonance and revolution frequencies.

With the SOLEIL parameters, for a cavity installed in a short straight section with $\beta_\perp \leq 5$m, dampings of 2500 and 1250 are necessary for respectively the highest longitudinal ($\approx$10 Ω) and transverse ($\approx$100 Ω/m) impedances.

The results of simulations [1] showed that first harmful HOMs could be damped enough to ensure beam stability in the ring by two pairs of classical couplers located on the inner beam tube. Since then, optimization of both coupler types (the first one, called "L-coupler", is dedicated to longitudinal modes with a loop parallel to beam axis and the other, called "D-coupler", is oriented perpendicularly to couple out the dipole modes), and measurements of the dampings on a prototype have been performed.

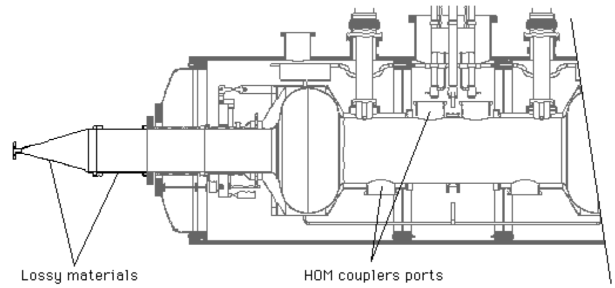

Fig. 1 : Layout of the cryostat with cavities and HOM dampers.

2 MEASUREMENTS OF HOM DAMPINGS

The highest impedance modes have frequencies below the cut-off frequency of the outer beam tube (676 MHz and 883 MHz for dipole and longitudinal modes respectively). Intensive calculations were performed to optimize the design of both RF structure and HOMs couplers with the goal to damp heavily these particular modes. Some important parameters of the structure, mainly the inner tube radius, the distance between cavity equators and coupler locations, were evaluated with the help of a home made code. Various designs of notch filter for the L-coupler were considered, and their responses as well as the values of the main constituent elements of both coupler types were determined from HFSS simulations.

With all these preliminary results, a prototype for performing measurements was fabricated. It consists of two copper cavities (CERN fabrication), a ϕ400 mm inner tube, assembled with ring pieces in order to change easily its length and the location of the couplers ports, and the ϕ260 mm outer tube. The geometry of the loop couplers can also be modified, since they are made of various sets of pieces and thus fully dismountable.

2.1 HOM couplers

Both coupler types were optimized by varying the capacitance or inductance of relevant elements and some coaxial lengths, in a frequency range up to the cut-off frequency of the outer beam tube. The geometry of the D-coupler (Fig. 2) is comparable with the geometry chosen for the LEP [2] or TTF [3] cavities. The coupling is provided by a loop located in a plane perpendicular to the beam axis, ended by a filter in order to insure the rejection of the fundamental mode ; the other capacitive and inductive elements (stub, series capacitor, etc.) increase the response of the coupler for some dangerous modes.

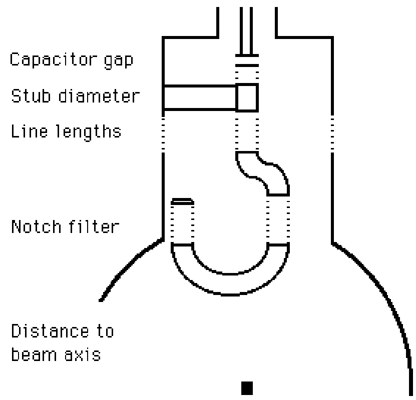

Fig. 2 : Sketch of the variable elements of D-coupler

For example, with a capacitor gap of 1.2 mm, a good equilibrium between the harmful HOM frequencies is obtained, as shown on the transfer function plot (Fig. 3). Obviously, this preliminary tuning of the elements is not sufficient, as it does not take into account the local variations of the HOMs fields components. Some slight changes are necessary after measurements of the dampings on the full prototype assembly.

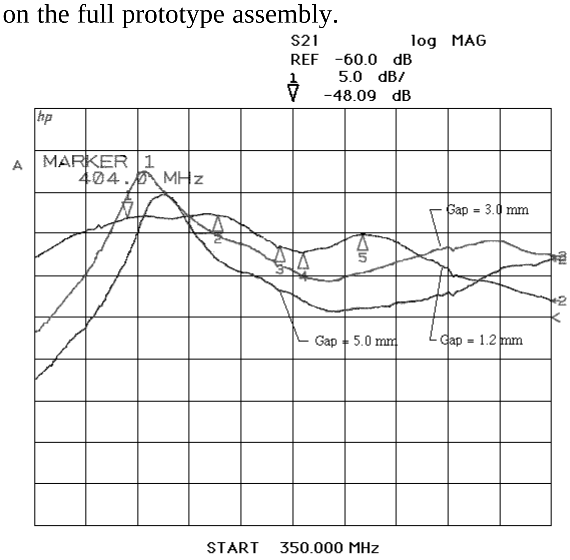

Fig. 3 : Transfer function of the D-coupler for various capacitor gaps.

The L-coupler (Fig. 4) has roughly the same inner structure as the D-coupler, but the loop is oriented in a plane parallel to beam axis to maximize Hϕ coupling and the fundamental mode is rejected by an additional L-C notch filter (oriented perpendicularly to loop plane. Some reactive elements allow to increase the response of the coupler on some cavity modes.

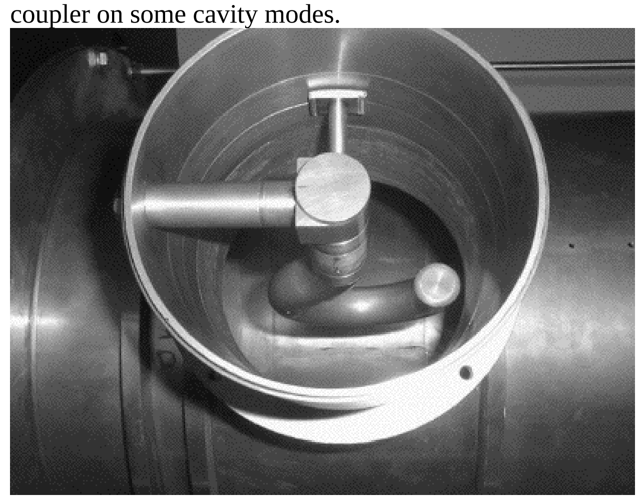

Fig. 4 : Part of the L-coupler.

2.2 *HOM dampings*

Once the main parameters of the couplers have been optimized, HOM dampings were measured on the copper prototype. For each tube length, the port location as well as the coupler geometry giving the best dampings was selected (see Fig. 5 for the results on the most dangerous dipole modes).

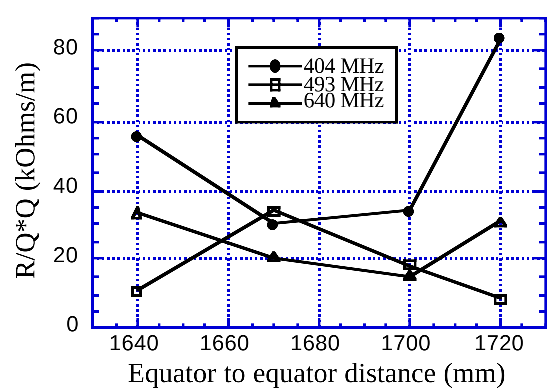

Fig. 5 : Dampings of the most dangerous dipole modes for different inner tube length.

The optimal geometry is characterized by the following values :

- distance between cavity equators : 1.696 m ($\approx 2\,\lambda_0$)
- distance from iris to D-coupler axis : 220 mm
- distance from iris to L-coupler axis : 500 mm

With an angle of 90° between the couplers, the dampings of some dipole modes are slightly higher. As this gain is not necessary, the angle of 115° is chosen (as for LEP and TTF cavities) in order to couple out part of quadrupole modes.

Due to the small distance between D-coupler and the iris of the nearest cavity (220 mm), the rejected power from the fundamental mode is quite important. For this reason, an internal cooling of the loop with liquid Helium is foreseen in order to guarantee its thermal stability. This is not necessary for the L-coupler for which a standard cooling by thermal conduction is adopted.

Freq. (MHz)	R/Q (Ω)	R/Q*Q	Freq. (MHz)	R/Q (Ω/m)	R/Q*Q
587	1.1	0.2 10^3	398	8.9	< 100
596	3.8	1.8 10^3	404	47.5	38 10^3
611	10.3	< 100	457	0.2	< 100
637	0.1	< 100	486	61.9	< 100
669	7.8	< 100	493	17.2	35 10^3
702	8.0	3.2 10^3	506	89.4	9.1 10^3
724	1.3	1.3 10^3	546	1.1	< 100
746	0.3	1.0 10^3	590	3.7	4.9 10^3
791	0.8	1.6 10^3	640	17.0	14 10^3
854	0.3	0.5 10^3	674	0.1	< 100

Tab. 1 : Longitudinal (left) and dipole (right) HOM dampings measured on the copper prototype.

After optimization of both structure and couplers, the dampings of the first harmful HOMs, measured on the copper prototype, fulfill the requirements [Tab. 1] with a large safety margin (at least a factor of four).

3 HIGH FREQUENCY HOMS

The design of the structure includes tapers linking the outer tube of the cavity to the vacuum chamber of the ring (Fig. 1). To guarantee a total dissipation of the modes propagating out the cavity at room temperature, these tapers will be fabricated with Stainless Steel 430 (which exhibits a very low equivalent conductivity, $\sigma_{eq}=\sigma/\mu_r$Û5.3 10^4 S, for frequencies under 4 GHz).

Two ports located outside of the cryostat are foreseen and can be equipped with classical room-temperature HOMs couplers in order to damp, if necessary, the eventual modes which could be excited by the beam.

Though they are not as dangerous as the ones studied in the previous section, we checked the effect of both tapers and couplers on the damping of the first 300 dipole and longitudinal HOMs propagating out the cavity (R/Q values are very small at higher frequencies). The results showed that the two pairs of L- and D-couplers, designed for the non-propagating modes, provide also efficient damping of the propagating modes. With the SS 430 tapers and these sole L- and D-couplers, the predicted threshold (calculated from the previous pessimistic formula, which assumes coincidence of HOM frequency with one single excitation spectral line and omit any damping line due to nearby modes) is above the design beam current for almost all high frequency modes.

4 CONCLUSION

The dampings of the first harmful longitudinal and dipole HOMs were measured on a copper prototype. After optimization, the required dampings were achieved with a large safety margin. Some important characteristics of the final design of the couplers were also defined after these measurements (e.g. cooling of the loop coupler, mechanical arrangement for the tuning of the notch filter).

HOMs of higher frequencies, i.e. above the cut-off frequency of the cavity beam-tubes, were also checked. The results are very promising since all these modes seem to be damped enough by the tapers and the two pairs of couplers, designed for the most dangerous non-propagating modes. The next milestone consists in testing at 4.2 K the Nb/Cu cavities, fabricated by CERN.

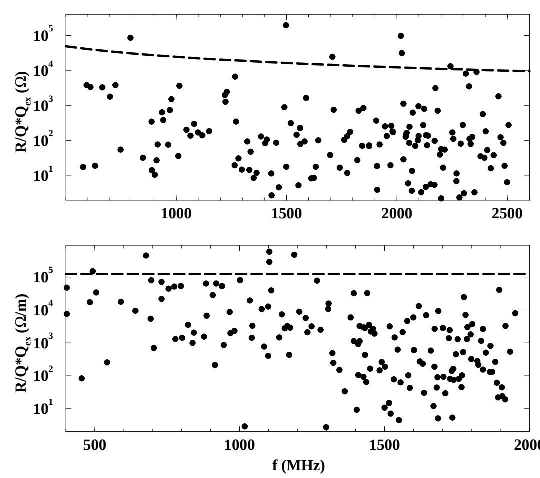

Fig. 6 : Damping of longitudinal (top) and dipole (bottom) HOMs by tapers and L- and D-couplers.

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