LONGITUDINAL BEAM STABILITY AND RELATED EFFECTS AT THE ALBA STORAGE RING

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Abstract

The risk of longitudinal instabilities excited by the narrowband and broadband resonator impedance was studied. A campaign for the search of modes trapped in vacuum chamber elements of the ALBA storage ring via electromagnetic simulation was initiated. Several critical vacuum elements in the ring like the vertical scraper, the injection and feedback kickers were identified. The outlets of the injection kickers had to be protected with RF-fingers whereas the scraper only produces dangerous modes in the withdrawn state, both do not pose a real problem. However, the calculated power distribution generated in the the feedback kickers could be an obstacle for the reaching the nominal current of 400mA. Furthermore, the budget of Z(n)/n of the storage ring was computed and checked on the risk of microwave instability using the Boussard criterion.

INTRODUCTION

ALBA is the Catalan/Spanish synchrotron radiation facility in commissioning phase at Cerdanyola de Vallés near Barcelona. As a third generation light source it will produce high brilliant photon beams on 7 beamlines (extendable up to 33 beamlines) in phase I. It is expected to run in user operation by the beginning of 2012.

IMPEDANCE RELATED ISSUES OF VACUUM CHAMBER DESIGN

The storage ring of only 268m circumference has a compact vacuum system design which contains many diagnostic elements. The risk of electromagnetic fields being trapped in or close to the dilatations or contractions of the various vacuum chambers has to be minimized. Apart from the possible excitation of longitudinal coupled bunch instabilities (LCBIs), the heatload created by the interaction of the beam spectrum with the longitudinal impedance is one of the key issues. So it was aimed at the detection of all narrowband resonances in the vacuum system. Only the cavities were not included, they are subject of another study.

Search for Trapped Modes

The search for dangerous modes was done for each element with the 3D EM-field solver GdfidL [1] in frequency domain taking into account its geometry and material distribution. The modes with their resonance frequency f_r, shunt impedance R_s, quality factor Q_{dis} and the modal loss factor $\kappa_L = \pi f_r (\frac{R_s}{Q}) F$ F being the gaussian form factor were computed. Under consideration of possible coherent superposition of wakes along the bunch train the modal loss factor has to be modified [2]:

$$\kappa_L \rightarrow \kappa_L \frac{D}{D^2 \sin^2(\pi \frac{f_r}{f_{RF}}) + 1} \quad (1)$$

where f_{RF} is the bunch repetition frequency (here synonymous with the RF-frequency) and $D = Q_L \frac{2 f_{RF}}{\pi f_r}$. Q_L is the loaded quality factor which yields by adding up parallel all quality factor contributions: $Q_L^{-1} = Q_{rad}^{-1} + Q_{dis}^{-1} + Q_{ext}^{-1}$. In this study, however, the contributions of Q_{rad} and Q_{ext} are often neglected which makes Q_L larger than it really is. This overestimates the power loss which is acceptable under a worst case assumption. If a resonance coincides with a harmonic of the RF-frequency, κ_L is enhanced by D, whereas if $f_r \approx f_{RF}/2$ it is suppressed by the same (reciprocal) factor assuming $D \gg 1$. The dissipated power in homogeneous filling is related to the loss factor by the well-known formula applied at nominal current $I_{tot} = 0.4$A:

$$P_{loss} = \frac{I_{tot}^2}{f_{RF}} \kappa_L = 0.32 \frac{A^2}{GHz} \kappa_L \quad (2)$$

The found mode spectra were compared to those of the real part of the longitudinal impedance in order to back up the eigenmode calculations. Finally the criterion of LCBI threshold was considered:

$$\kappa_L Q = \frac{\omega_s (E/e)}{f_0 \tau_L \alpha I_{tot}} = 1.475 \cdot 10^5 \Omega GHz \quad (3)$$

with ω_s as angular synchrotron frequency, f_0 as revolution frequency, τ_L as damping time, α as momentum compaction factor and (E/e) as energy in units of volts. BPMs, flanges, scrapers, injection and feedback kickers are now looked at due to their particular high risk.

BPMs

The first resonance of the BPMs (radius r=3.5mm) is very close to 12GHz, the 24th harmonic of the RF-frequency (0.5GHz). Under the assumption of coincidence $P_{loss} = \kappa_L \frac{I_{tot}^2}{f_{RF}} D$ The enhancement factor D is only 1.8 for $Q_L^{-1} = Q_{rad}^{-1} + Q_{dis}^{-1} = 68^{-1}$ which results in a total power loss of only 0.34W per buttom. However, the power fraction which is dissipated in the button is only $P_{dis} = \frac{Q_L}{Q_{dis}} P_{tot} = 0.22W$ which is even smaller and safe. However, the power loss of a larger bottom (r=5.15mm) under assumption of incoherent superposition reaches > 0.7W, under coherent superposition even more. Therefore it was discarded.

Flanges

3 resonances are below the cut-off frequency of which one is close to 4GHz (8^{th} harmonic of the RF-frequency) needs investigation. The dissipative Q_{dis} provided by GdfidL is 40.6 which leads to a enhancement factor of $D = 3.3$. But as the modal loss factor only is 0.33mV/pC due to rather small shunt impedance this leads only to a power loss of 0.34W. In fact, resonances coinciding with higher harmonics of the RF-frequency are less dangerous since in that case D is smaller.

Vertical Scraper

Its coupling impedance (Fig. 2 blue curve) is characterized by a large resonance close to the pipe's cut-off frequency which moves slightly as function of the scraper gap. In difference to the precedent elements, both resonance parameters R_s and Q are of rather high value. At a gap of 17mm, the scraper is already in withdrawn position, both resonance parameters reach such high values that the threshold of LCBIs is exceeded as it can be checked with (3) and (Fig. 2). However, at penetration in the beampipe deeper than the nominal position (9.5mm gap) no instability is excited. So this element does not represent an immediate danger of the beam stability but shows that cavities in the beam pipe are more dangerous than contractions.

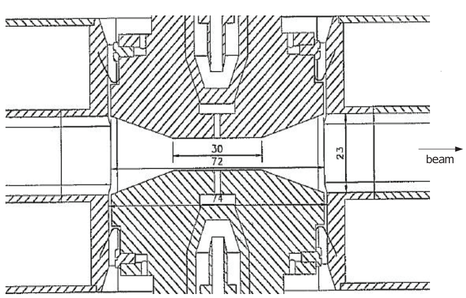

Figure 1: Vertical scraper at 9.5mm gap in a pipe of 23mm vertical extension . The scraper block of Cu, the beam pipe of stainless steel.

Injection Kickers

Their outlets $29x85mm^2$ are several mm larger than the ceramical pipe: $24x80mm^2$ (Fig. 3). Moreover, the outlets connect directly to the end flanges of the element which makes coupling between different cavities possible. This produces among others a double resonance at 6.1GHz below the pipe cut-off with $Q \approx 2269$ and $R_s \approx 500\Omega$ being already rather close to threshold of LCBIs. Therefore the beam was protected with RF-fingers against the cavities in the outlets (Fig. 4). They also have lips which partly separate the cavities in the outlets against the flange cavity. The resonances around 6.1GHz now only have shunt impedances around 10Ω, there is only one double resonance left whose quality factors are 34 times smaller than those of the resonances of the unprotected geometry. This reduces heatload as well as instability risk.

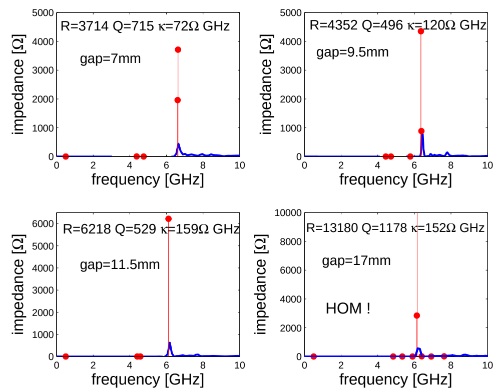

Figure 2: Superposition of coupling impedance' real part (blue) and eigenmode spectrum (R_s vs. f_r) (red) of the scraper in different positions.

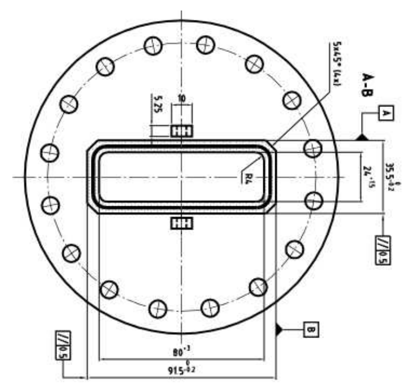

Figure 3: Injection kicker cross section, black line shows the contour of the exit pipes, the grey zone the ceramics.

Horizontal and Vertical Feedback Kicker

By selective activation of dissipation in material segments of the geometry the power repartition within both devices (Fig. 5) was computed for incoherent and coher-

Figure 4: The fingers installed in injection kicker outlets.

ent wake field superposition along the bunch train. Losses due to the external load (58% of the total) were considered. For incoherent superposition this leads to 44W loss in the vertical and 15.5W loss in the horizontal kicker. For coherent superposition, however, in the vertical kicker the loss is only 27W, whereas in the horizontal one it is 46W. For the latter one, 3 resonances, in particular one at 3GHz ($R_s = 163.3\Omega$, $Q_L = 1766$ and $D = 187.4$) is very close to a RF-harmonic. Under coincidence its modal loss factor $\kappa = 0.8\Omega$GHz is enhanced by D leading to total power loss of 48W of which $36.4W = 48W\frac{Q_L}{Q_{int}}$ remains in the kicker. For both power repartitions the temperature and stress distribution were calculated [4], but now it will be mainly reported on the coherent case. For that case the temperature of the electrodes of the horizontal one reaches locally $163°C$, 80°C more whereas the those of vertical one only reach locally $115°C$, 34°C less than in the incoherent case. The maximal stress is ~ 1000MPa at the locations where the ceramical bars hold the vertical electrodes. However, if loss of thermal contact of the electrodes to the ceramical bars due to distortion is considered, the stresses reach can values by far higher. However, some detuning of modes due to the distortion will probably alleviate it. Moreover, as an installation for the future it has been proposed to exchange the stainless steel connection bar in the horizontal kicker by a copper one to improve the situation.

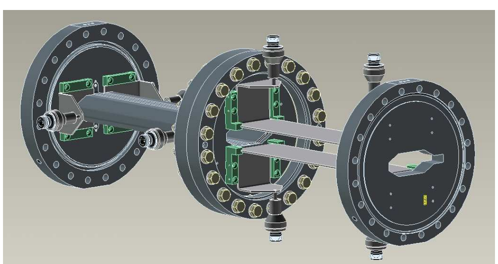

Figure 5: Feedback kickers.

$Z(N)/N$ BUDGET

The broadband and resistive wall impedance components were estimated against the threshold of the Boussard criterion (Chao p.262 [3]) being for ALBA $874m\Omega$ in homogeneous filling. The normalized beam power spectrum weighted $|Z/n|$ ($n = f/f_0$) will be used in the criterion denoted as $|Z/n|_{eff}$. As the modulus is taken before the beam spectrum averaging the real as well as the imaginary part contribute. For the resistive wall impedance chambers with a structured wall (marked with * in table 1) are described by 2-layer models while for the rest the thick wall model was applied. Whereas the 2-layer impedance of the in-vacuum undulator does almost not differ from the 1-layer one the 2-layer impedance of the NEG-coated Al-chamber is 44% higher compared to 1-layer description but its overall impact on the budget remains small. All contributions of the 1-layer chambers yield $158m\Omega$, however the 4 injection kickers produce $84m\Omega$ due to their thin Ti-cover of only $0.4\mu m$. A thicker coating, e.g. of $1\mu m$ would have produced only $35.7m\Omega$. The 2 elements with highest contribution are the cavities and the injection kickers whereas the installation of low-gap chambers only has small impact. On the other hand, the geometrical impedance was computed numerically by integration over the weighted $|Z/n|$ spectrum and yields a rather large value of $920m\Omega$. In fact, the real part of Z/n contributes a lot at low frequencies to $|Z/n|_{eff}$. Therefore the Boussard criterion is slightly exceeded but this will not really compromise the beam stability. Anyway, the stability against microwave can only be fully appreciated by tracking. The figures are nevertheless useful for comparisons with other synchrotrons.

Table 1: $|Z/n|$ Contributions

Chamber Type	**Z Type**	**#**	$\mathbf{|Z/n|_{eff}}$
1-layer chambers(251.6m)	RW	1	$158m\Omega$
inj.kicker*$(0.78m, 0.4\mu)$	RW	4	$84m\Omega$
NEG on Al-chamber*$(2.7m)$	RW	3	$6.37m\Omega$
in-vac undulator*$(2m)$	RW	3	$2.64m\Omega$
sub-TOTAL:	RW		$251m\Omega$
vacuum system +cavities	BBR	1	$920m\Omega$
TOTAL:	ALL		$1171m\Omega$

CONCLUSIONS

In homogeneous filling the ALBA storage ring does not have serious problems related to the longitudinal impedance. The vacuum chambers are safe in respect of LCBIs, however the feedback kickers could be very well affected by heatload. The strong magnetic fields necessary to allow all injection kickers to be in one straight section imposed a thin Ti-coating to the detriment of the resistive wall component of $|Z/n|$. This has potential of optimisation. Furthermore, smoother entrance in the ceramic chamber would reduce the risk of LCBIs and heatload without the use of RF-fingers. These issues, in the commissioning phase rather marginal, could become more critical once hybrid filling or other modes are served at high intensity.

ACKNOWLEDGEMENTS

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