MULTIMODAL INTERACTION IN THE ALS LONGITUDINAL FEEDBACK KICKER RF CAVITY*

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Abstract

RF cavities are essential components in particle accelerators not only for beam acceleration, but also for control purposes (bunch lengthening/shortening, deflecting and crabbing, transverse and longitudinal kickers) and for beam diagnostics (BPM). Normally, only a single resonating mode is actively used, although other modes can be excited by the circulating beam. Cavities used as longitudinal kickers for bunch-by-bunch feedback systems are designed with an axial mode, which, appropriately excited, provides a kick to the circulating bunches for maintaining beam stability. To provide the necessary bandwidth this mode has to be strongly damped resulting in quality factors of just a few units. In the longitudinal feedback kicker cavity just installed on the ALS we have detected a second axial mode which, although a few hundreds of MHz below the 1.4 GHz design mode, is also strongly damped and has a shunt impedance high enough to be appreciably excited by the feedback amplifier coupling to the first mode. In this paper we show bench measurements on the cavity and with beam during its commissioning and discuss the interaction of the two modes resulting in a modulation of shunt impedance and phase response.

INTRODUCTION

The Advanced Light Source main storage ring relies on a longitudinal feedback system to suppress multibunch instabilities and be able to operate at its design current of 500 mA [1]. At the end of 2015 the original transmission line longitudinal kicker was replaced by a much shorter device, based on a heavy loaded RF cavity, in order to make space for a new insertion device.

Table 1 lists the ALS relevant parameters. The maximum voltage that the kicker needs to supply can be estimated from

$$V_{\max} = 2\frac{1}{\tau_{\varepsilon}} T_0 \frac{E_0}{e} \Delta\varepsilon_{\max} \approx 400\ V \qquad (1)$$

where τ_{ε} is the longitudinal damping time, T_0 the ring's revolution period, E_0 its energy and $\Delta\varepsilon_{\max}$ the maximum energy spread.

The kicker cavity consists of a stainless steel pillbox cavity loaded by four ridged waveguides on each side (Fig.1).

Table 1: Relevant ALS Parameters

RF Frequency	499.65 MHz
Harmonic Number	328
Beam Energy	1.9 GeV
Beam Current	500 mA
Long. Damping Time	6 ms
Max. Energy Spread	$< 1\cdot10^{-3}$
Req. Kicker Voltage	~ 400 V

The four upstream feedthroughs are connected to the feedback amplifier and the others to external loads.

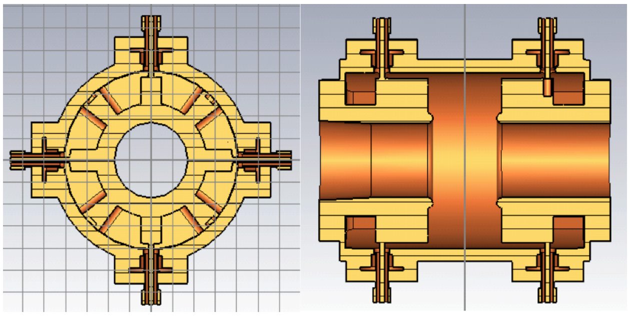

Figure 1: Transverse and longitudinal sections of the ALS longitudinal feedback kicker cavity.

The resulting quality factor decreases to a value around 5, which allows satisfying the minimum bandwidth requirement given by

$$\Delta f_{-3dB} \geq (p \pm 0.25) f_{RF} \qquad (2)$$

where p is any non-zero integer and f_{RF} the main RF frequency.

The cavity is not too dissimilar from the one in use in the BESSY II storage ring [2], with the exception of a larger, circular beampipe aperture, to match the ALS vacuum chamber shape in the installation straight, and the addition of "nosecones" to partly compensate the consequent reduction in shunt impedance. It should be noted that a larger pipe aperture is beneficial from the point of view of trapped high-order modes.

The design parameters of the ALS cavity are summarized in Table 2. A first series of computer simulations using SuperLANS [3] and HFSS [4] were carried out yielding results in line with those reported for BESSY II and DAΦNE [5].

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Table 2: Kicker Cavity Specifications

Pillbox Length	72 mm
Overall Length	283 mm
Pillbox Radius	83 mm
Beampipe Radius	35 mm
No. of Waveguides	8
Center Frequency	1383 MHz
Bandwidth (-3 dB)	276 MHz
Shunt Impedance	657 Ω

BENCH MEASUREMENTS

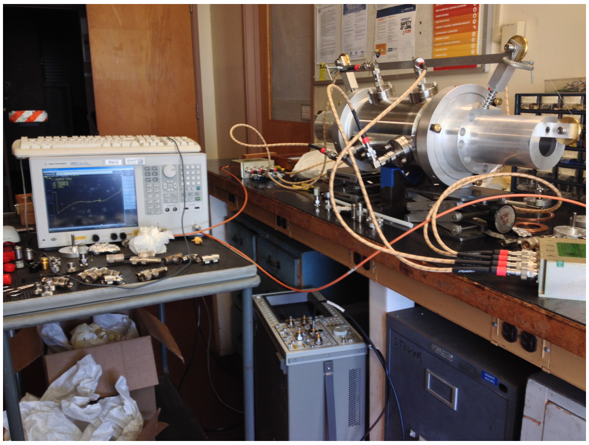

Figure 2: Cavity undergoing RF bench tests.

A number of RF tests were performed on the completed cavity. It is worth pointing out that with such a low quality factor the standard bench test techniques become more difficult. The most reliable information is obtained from transmission measurements between the upstream ports excited symmetrically and the downstream ones combined in-phase through the use of RF splitters as shown in Fig.2. It must be noted that such measurement does not assure that the coupling between ports takes place through a longitudinal mode.

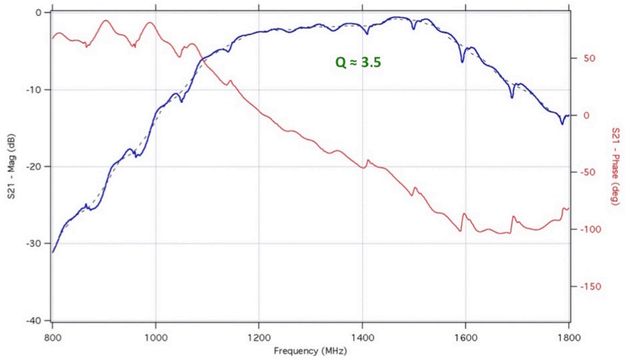

Figure 3: Transmission between ports for the fully loaded cavity.

Figure 3 shows the response obtained in correspondence of the cavity's operating frequency, where a lower than expected Q value, around 3.5, was measured. To understand the nature of this discrepancy, we repeated the measure for a cavity with reduced loading (by removing two downstream couplers), obtaining the double-peaked response showed in Fig.4.

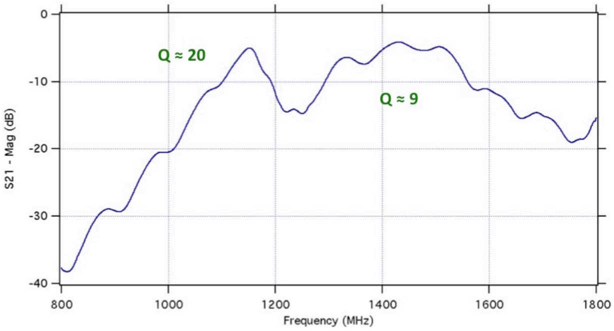

Figure 4: Transmission between ports for a reduced-load cavity.

By perturbative measurements, possible due to the higher Q, we confirmed that both peaks correspond to modes with longitudinal field on axis.

3D COMPUTER MODELLING

A new set of computer simulations was performed to identify the origin of this second mode, which had not been reported for similar cavity designs.

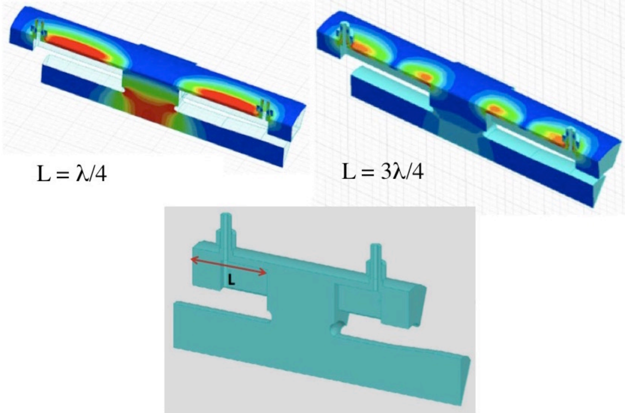

Figure 5: λ/4 resonances on the waveguide loads.

We identified λ/4-type resonances along the waveguide length. These modes originate from the impedance mismatch between ridged waveguide and feedthrough coupler and the 80 mm long ridge in our design causes the lower order resonance to be around 1100 MHz.

Table 3: Cavity Modes List

Freq. (MHz)	Q_L	R/Q
1110.3	4.0	43
1184.5	2.8	< 1
1204.5	2.8	0
1204.6	2.8	0
1223.6	2.8	0
1231.9	2.9	0
1231.9	2.9	0
1259.9	2.9	0
1498.0	8.7	52

Furthermore, since in the complete model there are 8 such waveguides, there are also 8 independent modes of oscillation in the structure, which are listed in Table 3. The analysis of these modes shows that only one of them has a substantial longitudinal field on axis, with a shunt impedance of the order of 200 Ω. Therefore of comparable magnitude with the TM010 fundamental mode of the pillbox cavity.

Figure 6 shows a projection of the longitudinal field intensity on the x and y planes for both axial modes.

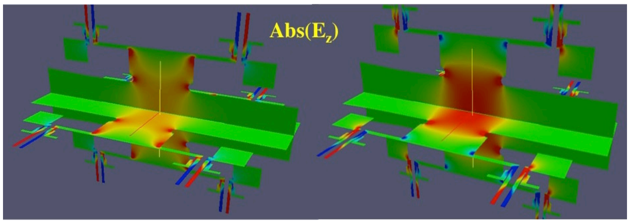

Figure 6: Longitudinal electric field normalized intensity projected on the x=0 and y=0 planes for the λ/4 resonance (left) and the TM010 mode (right).

INTERACTION BETWEEN RESONANCES

The presence of the additional longitudinal mode identified in the previous section affects the overall response of the kicker. Both modes generate a longitudinal electric field interacting with the bunches, but their simultaneous response to a given amplifier excitation is different since their natural resonating frequencies are different as well as their Q, in general.

A mode of resonant frequency f_1, excited at a frequency f, has an asymptotic response phase-shifted from the excitation by an amount [6]

$$\Delta\varphi_1 = \arctan\left(Q\frac{f_1^2 - f^2}{f_1 f}\right) \qquad (3)$$

Additionally, the response amplitude A_1 is decreased from its on-resonance excitation value A_0 by

$$\frac{A_1}{A_0} = \frac{1}{\sqrt{\left(Q\frac{f_1^2 - f^2}{f^2}\right)^2 + \frac{f_1^2}{f^2}}} \qquad (4)$$

If now we have two separate modes resonating at frequencies f and f', evidently for each given excitation at a frequency f_1, the two modes responses (i.e. the longitudinal field on axis) will be phase shifted by a total amount $\Delta\varphi_1 + \Delta\varphi_1'$. If this quantity is larger than π/2, there will be partial cancellation between the two modes fields, with consequent reduction in total shunt impedance. Even for smaller phase differences, the total phase transfer function can deviate from the ideal linear response affecting negatively the feedback processing electronics. Eq.(4) mitigates the problem, since large phase differences come with large reduction in the amplitude of at least one of the two modes.

Finally, from the Q values reported in Tab.3, considering that the time constant of a resonance is

$$\tau = 2Q/\omega \qquad (5)$$

we see that the longitudinal modes have τ's of the order of a nanosecond or shorter. Since the feedback operates in the 1.2-1.5 GHz band, it means that the asymptotic values derived in Eqs.(3-4) are to be intended as worst case scenarios: the instantaneous frequency being intermediate between the excitation and the free-oscillator frequencies.

We recently started operations with the new kicker cavity and phase shifts between the two longitudinal modes, conservatively estimated to be at most 60-70 deg do not seem to be affecting the feedback system electronics. More systematic studies are underway, however.

CONCLUSIONS

In this paper we reported on the unexpected presence of a second mode with longitudinal field on axis in the heavily damped RF cavity designed as a kicker for the ALS longitudinal feedback system. This second mode, resonating at a frequency within the feedback bandwidth is generated by λ/4 resonances in the cavity ridged waveguides.

Although in principle the presence of two modes could negatively impact the feedback performance, an initial summary analysis and first operations on the ALS indicated that this should not be the case.

REFERENCES

[1] D. Teytelman *et al.*, "Operation and Performance of the PEP-II Prototype Longitudinal Damping System at the ALS", in *Proc. of PAC '95*, Dallas, TX, USA May 1995, paper RAE12, pp. 2420-2422.

[2] S. Khan *et al.*, "Longitudinal and Transverse Feedback Kickers for the Bessy II Storage Ring", in *Proc. of PAC '99*, New York, NY, USA, Mar. 1999, paper TUA33, pp. 1147-1149.

[3] D.G. Myakishev and V.P. Yakovlev, "The New Possibilities of SuperLANS Code for Evaluation of Axisymmetric Cavities", in *Proc. of PAC '95*, Dallas, TX, USA, May 1995, paper MPC17, pp. 2348-2350.

[4] http://www.ansys.com/Products/Electronics/ANSYS-HFSS

[5] R. Boni *et al.*, "A Waveguide Overloaded Cavity as Longitudinal Kicker for the DAΦNE Bunch-by-Bunch Feedback System", in *Part. Acc.*, vol.52, p. 95, 1996.

[6] S. De Santis *et al.*, "Analysis of Resonant TE Wave Modulation Signals for Electron Cloud Measurements", in *Proc. of IPAC 2012*, New Orleans, LA, USA, May 2012, paper MOPPR073, pp. 957-959