SIMULATIONS AND MEASUREMENTS OF HIGHER ORDER MODES OF THE ELETTRA RF CAVITIES IN VIEW OF COUPLED BUNCH INSTABILITY COMPENSATION BY TEMPERATURE VARIATION

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ABSTRACT

Coupled Bunch Instabilities (CBI), driven by beam-cavity interactions are cured in ELETTRA by temperature tuning of the cavities [1]. To allow a theoretical prediction, the impedance of the parasitic cavity modes must be evaluated over the temperature tuning range. Interaction between beam Coupled Bunch Modes (CBM) and cavity Higher Order Modes (HOM) is predicted analytically using as input the database in which all the results of measurements and simulations concerning the ELETTRA cavities are collected. New simulations with URMEL-T were performed in order to complete the database for a realistic cavity layout, including the 30 cm long drift tubes. The longitudinal and transverse coupling impedances are calculated using the URMEL-T R/Q and the measured Q. Secondary effects of the temperature tuning method have been observed and are discussed. After longitudinal stability has been reached transverse effects are observed. To get rid of them an adjustable version of the Higher Order Mode Frequency Shifter (HOMFS) has been designed. The characterization of this version is presented.

ACTUAL VALUE OF IMPEDANCE

The nine longitudinal cavity HOMs resonating below the cut-off frequency of the beam tubes have now been completely characterized. This includes the computation of the R/Q for the actual cavity configuration and the measurement on the storage ring cavities of the resonant frequency f_r, the quality factor Q, the coefficients τ (temperature) and φ (Δf_r for unit RF frequency change).

HOM	fr @ 48 °C MHz	R/Q Ω	Q	R kΩ	τ kHz/C	φ
L1	949.506	28.8	35300	1017	-11.5	0.63
L2	1057.199	0.7	33700	24	-19.3	-0.31
L3	1421.456	5.0	39300	197	-43.1	-2.16
L4	1514.638	4.9	17400	85	-28.2	-0.31
L5	1606.348	9.1	18100	165	-41.6	-2.33
L6	1876.971	0.3	41100	12	-33.4	-0.14
L7	1948.475	1.8	33100	60	-51.2	-2.30
L8	2072.036	0.1	12500	1	-110.9	-8.94
L9	2124.792	7.7	27000	208	-111.4	-9.30

Table 1: Longitudinal cavity parasitic modes

The parameters in table 1 are as measured on cavity S3 after installing the HOMFS, except for R/Q which is a computed value. The threshold currents for modes L2 and L6 are larger than 120 mA, for mode L8 1100 mA. Thus the unstable temperature intervals for L2 and L6 are narrow and so far they never coupled to the beam, as well as those HOMs resonating above the cut-off of the cavity beam tubes but below that of the vacuum chamber.

HOM	fr @ 48 °C MHz	R/Q⊥ Ω	Q	R⊥ MΩ/m	τ kHz/C	φ
T1a	743.169	4.6	40000	2.9	-36.3	-3.1
T1b	743.303	4.6	39900	2.9	-36.0	-3.1
T2a	745.280	15.8	35300	8.7	-13.5	0.0
T2b	746.463	15.8	36200	8.9	-11.5	0.0
T3a	1114.274	13.0	37100	11.2	-18.5	0.2
T3b	1114.706	13.0	35500	10.8	-16.1	0.5
T5a	1241.307	4.5	17800	2.1	-49.7	-4.0
T5b	1242.237	4.5	17800	2.1	-49.7	-3.9
T6	1304.342	0.3	23200	0.2	-38.9	-2.3

Table 2: Transverse (dipole) cavity parasitic modes

$(R/Q)_\perp$ in table 2 is as calculated by URMEL (voltage integrated along the beam tubes radius, 5 cm). fr, Q, τ and φ are measured on cavity S3 at 48 °C. T2 and T3 are unstable over a large temperature range, like L1 in the longitudinal case, since the coefficient τ is rather low. If their unstable range coincides with the temperature tuning range a HOMFS is needed to get rid of them.

2 SECONDARY EFFECTS

2.1 Cross-talk between cavities

A temperature scan on a cavity is equivalent to scan different CBI excitation levels. Starting from stability, at low CBI excitation levels the beam performs coherent longitudinal oscillations. At higher excitation low frequency, longitudinal oscillations (LFO's) are observed whereby a rapid increase in coherent motion decoheres causing bunch dilution and lifetime increase. Also a fictitious increase in the rms of the variation of each Beam Position Monitor (BPM) reading is observed, due to the sampling rate of their electronics. [2, 3]

Fig. 1 shows the result of a scan from 51.5 °C to 57.0 °C on cavity S9 at 250 mA, 2.0 GeV. Cavity S3 temperature is kept fixed at 65.0 °C. In this condition CBM 92 and 388 are slightly above the instability threshold due to the interaction with the longitudinal coupling impedance of the parasitic modes L5 and L7 in cavity S3. When TS9 is 51.5 °C the longitudinal motion is coherent. The CBM 92 and 388 phase oscillation amplitudes are 5° and 9° respectively, the BPMs' rms are 5 μm and the lifetime is 7 hours. When TS9 is 52.0 °C, also CBM 363, driven from the coupling impedance of

HOM L3 in cavity S9 (fig. 2) is present in the beam spectrum. The beam motion is coherent but without LFO's. When TS9 increases to 53.0 °C, where the driving impedance for CBM 363 is increased, LFO's begin. As a consequence CBM 92 becomes stabilized. At 54.0 °C the maximum coupling is reached and the LFO's amplitude reaches a maximum. The BPMs' rms are larger than 100 µm and the lifetime is as large as 20 hours. Now also CBM 388 is stabilized. At 55.0 °C we leave the strong interaction region for CBM 363, thus the process is reversed and mode 388 is destabilizing again. Finally at 56.0 °C the CBM 363 is again stable, and both mode 92 and 388 are again performing a coherent beam oscillation. Hence the unstable oscillation of the CBM 92 and 388, determined by TS3 at 65.0 °C, is heavily influenced by the setting of TS9 in the interval 52-57 °C where the contribution to the coupling impedance for these CBMs is negligible. This is what we call the cross-talk between cavities.

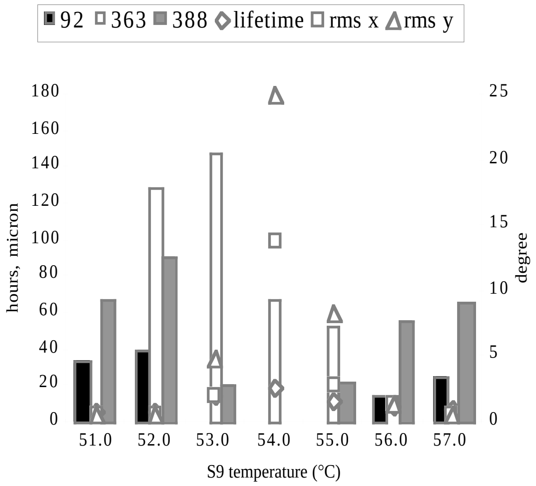

Fig. 1: Cross-talk between cavity S3 and S9.

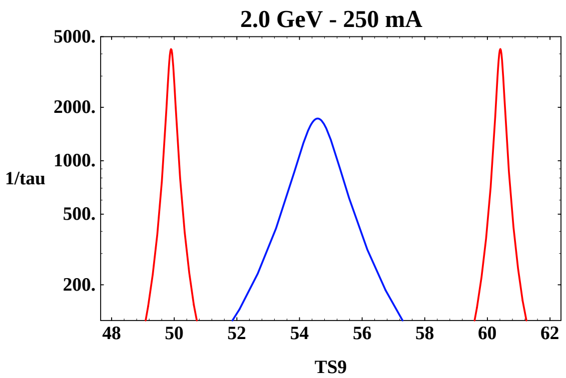

Fig. 2: CBM growth rates for TS9 48-62: in the centre of the range CBM 363, left and right CBM 104 and 103.

The mechanism proposed to explain the cross-talk between cavities takes into account the bunch dilution. Let us suppose that the temperature of a first cavity is kept fixed and that the beam drives in this first cavity an impedance just above the instability threshold, as calculated for the nominal bunch density. The result is a coherent coupled bunch beam oscillation. Then we begin to change the temperature on a second cavity, introducing a second, much stronger, driving source for a coupled bunch beam instability. If the driving source delivered by the second cavity is strong enough, the beam oscillation decoheres with the result of an effective bunch lengthening and a dilution of the beam density. As an effect of the bunch dilution, the growth rate of the CBM driving the low impedance in the first cavity, which temperature has been kept fixed, decreases below the instability threshold and the CBM oscillation stabilizes. Eliminating the strong driving source by a further change in temperature of the second cavity, the beam oscillation becomes coherent and the CBM interacting with the first cavity destabilizes.

2.2 Cavity temperature oscillation

By changing the temperature of cavity S9 to 50 or 60 °C (CBM 104 and 103, fig. 2) the beam couples to the impedance of HOM L9 and the cavity temperature starts to oscillate by ±1-2 °C, if the beam current is sufficiently intense. For short bunches, the L9 power can attain rather high values if the beam current's frequency line coincides with the HOM frequency. Already at the limit of the interaction region (59.5-61.5 °C in fig. 2), some kilowatts of power are dissipated into the cavity walls. Thus the temperature increases and moves outside the interaction region, before the temperature regulation loop can compensate it. Outside the interaction interval no L9 power is anymore dissipated in the cavity, the temperature decreases and the process restarts, generating in this way a temperature oscillation. Correspondingly we see the CBM amplitude oscillating on the spectrum analyzer. This effect can be observed only by exciting cavity HOM L9, because it has the highest temperature coefficient, with a very narrow peak in temperature. Via the cross-talk effect a temperature change in one cavity can cause a temperature oscillation in another one, if mode L9 is involved.

2.3 Spurious vacuum interlocks

Each cavity is equipped with an ion pump and a cold cathode gauge. They are mounted on the cavity on two equatorial ports with CF100 flanges (ϕ 84 mm) without any grid in-between. The pressure readings control a vacuum interlock. Spurious vacuum interlocks have been observed to be caused by the beam exciting a HOM in the cavity, whose electromagnetic field penetrates through the port into the vacuum device generating false high pressure readings. The effect is beam current dependent.

By correlating the acquisitions of the beam spectrum, the growth rate computations and the temperatures at which these spurious interlocks happen, we have identified HOMs L5 and L9 as the source for these effects. L5 resonates at 1600 MHz and has a rather strong field in the equatorial region, while L9 resonates at 2120 MHz. Both interact strongly with the beam, due to the strong shunt impedance. As before for the temperature oscillation, via the cross-talk effect a temperature change in one cavity can cause a spurious vacuum interlock in another one, if mode L9 is involved.

3 HOMFS CHARACTERIZATION

The need for a HOMFS on cavity S3 is clearly demonstrated from the computed growth rates plotted in fig. 3. The growth rate of CBM 389 is larger than the radiation damping rate (126 s^{-1}) over almost the whole tuning range 40-70 °C. The HOM L1 frequency must therefore be shifted outside the tuning range. A fixed HOMFS has thus been mounted on cavity S3.

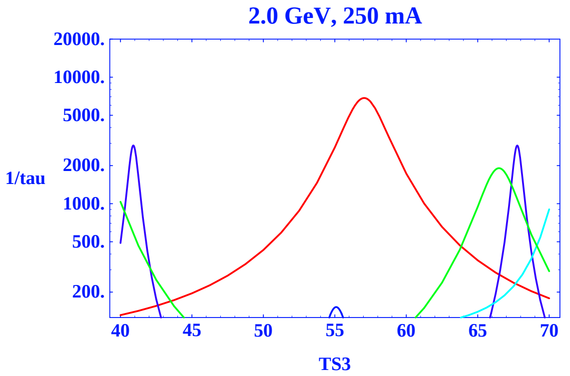

Fig. 3: No stable windows on S3 without HOMFS.

The growth rates computed after the installation of the HOMFS on cavity S3 are shown in ref. [4]. Now two stable windows are available, even if there were three more HOMs included in the computation (L7, L8, L9). CBM 389 disappeared completely from the temperature tuning range. Now only CBM 363 or 365, driven by HOM L3 in cavity S3 at 51 °C or in cavity S9 at 53 °C, are excited at a reduced level and used for the relaxed operations mode with increased lifetime [3]. After stabilizing longitudinally the beam, transverse instabilities driven by coupling impedances of the dipole parasitic cavity modes are excited. The most harmful mode is the HOM T3; due to the similar τ and Q, it behaves in temperature like L1 does. Thus an improved adjustable version of the HOMFS has been designed with a copper cylinder moving inside one equatorial port of the cavity. From this we get two contributions to the frequency shift. The effect of the HOMFS itself is low for those HOM with low field in the equatorial region, like L1. But one of the culprits for the spurious vacuum interlocks, L5, shifts by 3 MHz, confirming the high field intensity. Furthermore the accelerating mode is shifted by $\Delta f_0 \sim +600$ kHz. When the external tuning cage tunes f_0 to the nominal f_{RF} there is a second shift for each HOM, $\varphi * \Delta f_0$, of the same sign as the first one. The two terms sum up to a consistent frequency shift. The temperature shifts for the various modes are shown in fig. 4 as a function of the HOMFS position. In the range from 30 to 40 mm the HOMFS penetrates inside the cavity. The fixed HOMFS is at the position of 30 mm, that is with the adjustable one we can gain up to 50%.

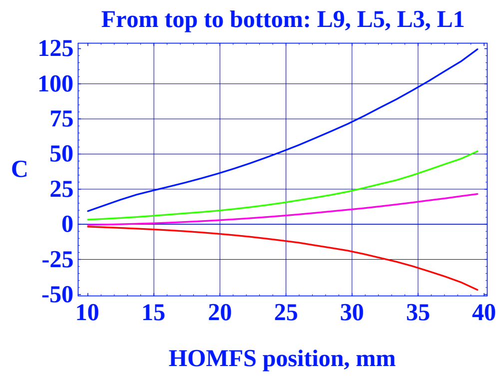

Fig. 4: Adjustable HOMFS shift for a selection of HOM

Finally in fig. 5 we predict the shift on cavity S9 for the transverse HOM T3 when the HOMFS slightly penetrates into the cavity (reference +38 mm). The goal of shifting T3 outside the tuning range is achieved. The adjustable HOMFS will be installed soon on cavity S9.

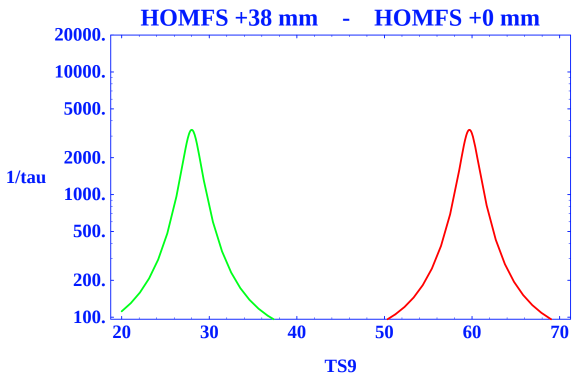

Fig. 5: Effect of the HOMFS on the dipole HOM T3

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