HOM CHARACTERISATION OF THE ANKA RF CAVITIES FOR COUPLED BUNCH INSTABILITY CALCULATIONS

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Abstract

The Higher Order Modes (HOM) spectrum of the first RF cavity of the ANKA storage ring has been fully characterised. Possible beam-cavity interactions leading to unstable longitudinal and transverse coupled bunch oscillations have been then analysed as a function of the cavity temperatures. Proper temperature settings are computed in view of the commissioning start of ANKA, scheduled for the end of 1999.

1 INTRODUCTION

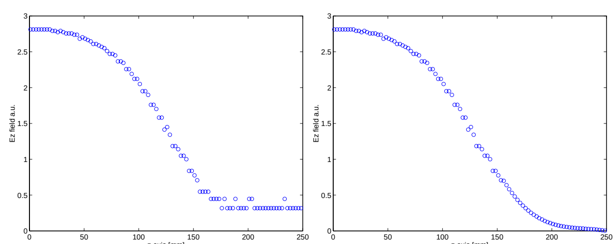
The ANKA storage ring cavities are of the Elettra-type. Some improvements have been introduced on the cooling circuit, to improve its efficiency [1]. Coupled Bunch Instabilities will be cured following the same approach than in ELETTRA, that is using the mode shifting technique by cavity temperature tuning and with the additional degree of freedom of the HOM Frequency Shifter. This requires full characterisation of the HOM spectrum to identify any possible beam-cavity interactions. As foreseen by the time schedule, by the end of February one out of four ANKA cavities was fully characterised and tested at the ELETTRA laboratory (cavity ANKA_1), while a second one was under test (cavity ANKA_2). The cavity characterisation follows a standard procedure which foresees the measurement of the fundamental cavity mode parameters included in the acceptance test protocol, like frequency, quality factor and R/Q, and the identification of the HOM. HOM measurements include frequency, quality factor and, for longitudinal modes, the R/Q. Transverse dipole modes are identified with field measurements. Field measurements have been performed with the cavity at atmospheric pressure, under nitrogen flux to prevent cavity surface pollution. The frequency and the quality factor are measured with the cavity under vacuum.

2 THE LONGITUDINAL MODES

The resonance frequency of the longitudinal modes up to the cut off frequency of the cavity beam pipes has been computed with MAFIA 4.0. The real value of the mode frequency is found for each cavity by identifying the electric field along the beam path for those peaks resonating close to the computed value. After mode identification the R/Q has been measured with the perturbation method, that is by measuring the frequency shift caused by a bead moving along the beam path. The measurement set-up is the same already used to characterise ELETTRA cavities [2]. The loaded value of the quality factors are measured with the Network Analyser HP 8510B in transmission mode. The unloaded values are then computed by taking into account the coupling coefficients β of the Input Power Coupler and of the RF signal pick-ups mounted on the cavity.

2.1 R/Q and Q of the accelerating mode

Particular care has been dedicated to the evaluation of the shunt impedance of the accelerating mode L0 which defines the cavity acceleration efficiency. The perturbing bead for the L0 mode is a stainless steel calibrated needle [2]. The frequency shift measured along the beam axis for this mode is shown in fig. 1a. To eliminate the noise that occurs at the tails of the measurement, where the frequency shifts introduced by the bead can be compared to the measurement error, the noisy data are interpolated with a polynomial curve of order 3. Figure 1b shows the interpolated curve after the fit. The R/Q and Q values measured on the first two ANKA cavities are listed in table 1.



a b

Fig. 1: L_0 Electric field on half cell: measured (a) and interpolated data (b).

Table 1: R/Q and Q measured values of the longitudinal accelerating mode (Transit time factor 0.700)

Cavity	R/Q (Ω)	Q	Rsh (MΩ)
ANKA_1	174.2	39000	3.33
ANKA_2	174.5	41200	3.52

The Q factor could be improved in the second cavity after a modification in the fabrication procedure, avoiding the diffusion of the filler material on the inner cavity surface during the brazing process [3].

2.2 R/Q and Q of the HOM longitudinal modes

The comparison of the computed on-axis electric field profile with the measured one allows safe identification of each HOM. The measurement of the electric field becomes

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critical for modes resonating close to the cut-off frequency of the beam ports, like mode L9. In this case the field begins to penetrate into the beam tubes. To perform the measurement a 300 mm tube, diameter 100 mm, is then connected to the beam port. This reproduces fairly well in the laboratory the situation on the machine where there are bellows and connection tubes on each side of the cavity. In figure 2, the computed field (solid line) can be compared with the measured one (dotted line).

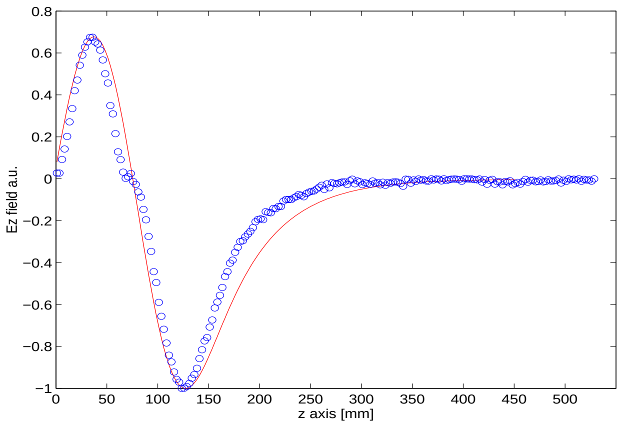

Figure 2: Measured electric field on half cavity length for the L9 mode (dotted line), compared with the computed field (solid line).

The parameters of the nine longitudinal modes below cut-off as measured on cavity ANKA_1 are listed in table 2 along with the computed ones. The computed R/Q of mode L8 (frequency 2088 MHz) is close to zero, resulting in an impedance below the threshold to excite coupled bunch oscillations; in fact it is not possible to measure it.

Table 2: Cavity ANKA_1 longitudinal modes

mode	fr, MHz measured	R/Q, Ω comp.	R/Q, Ω meas.	Q computed	Q measured	R_{sh}, kΩ measured
L1	947.0	29.3	27.6	46900	36200	1000
L2	1056.3	0.7	1.0	66600	48400	48
L3	1421.6	5.0	5.1	57800	44400	226
L4	1511.4	4.8	4.2	63500	46000	193
L5	1604.6	9.8	9.8	79100	44800	439
L6	1875.6	0.4	0.5	59000	39400	20
L7	1947.8	1.6	1.6	83600	67900	109
L8	n.m.	0.0	n.m.	63400	n.m.	n.m.
L9	2126.7	7.8	7.8	53700	32400	253

Cavity ANKA_2 characterisation is not yet completed. Table 3 shows the data for the two modes with the highest shunt impedance, L1 and L5.

Table 3: Selection of measured data, cavity ANKA_2

mode	fr, MHz	R/Q, Ω	Q	R_{sh}, kΩ
L1	947.3	26.7	37500	1001
L5	1605.6	10.3	48200	496

3 DIPOLE MODES

The first nine dipole modes resonate below the cut off frequency of the beam pipe and are therefore trapped into the cavity. If their frequency overlaps exactly a line of the beam spectrum, their transverse impedance can excite transverse coupled bunch instabilities in ANKA [4]. However, using the mode shifting technique in Elettra, only modes D2, D3 and D5 interacted sometime in the past with the beam. To identify the dipole modes we start from the MAFIA frequency list and select the dipole modes using the perturbation method. In fact we look for modes with electric and magnetic field on the beam axis, while sextupole modes have zero field on the axis. This is particularly important to identify the mode D3 which resonating frequency is very close to that of mode S1. Due to the asymmetries in the cavity geometry, each dipole mode generates two polarisations, which we call *a* and *b*, resonating at slightly different frequencies. Only one polarization could be measured for modes D5 and D8. Table 4 lists the measured value of the resonance frequencies and quality factors, while (R/Q)' is given by MAFIA.

Table 4: Cavity ANKA_1 dipole modes

Mode	fr, MHz	(R/Q)', Ω	Q	$R_\perp$, MΩ/m
D1a	743.73	4.7	35500	2.6
D1b	743.94			
D2a	746.39	15.8	36400	9.0
D2b	746.71			
D3a	1112.48	13.0	33200	10.1
D3b	1112.65			
D4a	1220.33	0.1	78400	0.2
D4b	1220.79			
D5	1244.80	4.5	24000	2.8
D6a	1304.89	0.3	15000	0.1
D6b	1305.07			
D7a	1557.29	0.0	7600	0.0
D7b	1557.74			
D8	1631.28	2.4	22000	1.8
D9a	1716.08	1.6	18100	1.0
D9b	1716.32			

4 COUPLED BUNCH INSTABILITIES

The use of Elettra-type cavity, with a cooling system layout similar to the Elettra-one, will allow to cure Coupled Bunch Instabilities (CBI) in ANKA by mode shifting, as successfully experienced at ELETTRA. It has already been demonstrated in [4] that both for longitudinal and transverse oscillations a proper setting of the temperature of the cavities can guarantee stable machine operation for ANKA at 2.5 GeV, up to 400 mA of stored beam. The situation can be more critical at lower energies, particularly at the injection energy of 500 MeV, where transverse effects could disturb the machine operability. To avoid this it will probably be necessary to excite a longitudinal mode on purpose to increase the thresholds for the transverse ones, as it is done in ELETTRA. The calculations presented in [4] where performed on random generated frequencies, starting from the statistical spread of HOM frequencies observed in the existing Elettra-type cavities. Now we want to verify on the first real cavity for the ANKA storage ring that stable intervals are actually available and to give a first indication of what will be the temperature settings for that cavity.

Table 5: ANKA Storage Ring parameters

Parameter	Design Value
Energy, E/e	2.5 GeV
Momentum Compaction, α	8.1 10^{-3}
Beam Current, I_b	400 mA
RF frequency, f_{RF}	499.652 MHz
Revolution frequency, f_0	2.7155 MHz
Harmonic number, h	184
Long. Rad. Damp. Time, τ_ε	1.45 ms
Hor. Rad. Damp. Time, τ_x	3.08 ms
Ver. Rad. Damp. Time, τ_y	2.96 ms

The growth rates of the longitudinal Coupled Bunch (CB) modes have been computed as a function of temperature for cavity ANKA_1, following the usual approach [5]. The cavity data are those listed in table 2 and the ANKA machine parameters are shown in table 5. The result for a stored beam of 400 mA (184 equally filled and spaced bunches) at 2.5 GeV, is shown in figure 3. Growth rates above the radiation damping rate, leading therefore to unstable coupled bunch oscillations, are computed for CB number 165 between 41 °C and 44 °C (interacting with cavity mode L7); for CBN 46 between 56 °C and 60 °C (cavity mode L9); for CBN 155 between 56 °C and 60 °C (cavity mode L3). Two stability windows are present between 45 °C and 55 °C and between 62 °C and 69 °C.
The calculation for the transverse horizontal case shows a significant excitation for CBN 86 between 40 ° and 47 °C (figure 4). The machine is slightly less sensitive to vertical CB oscillation, due to the lower value of the betatron function at the cavity location, which is less than half the horizontal value [4]. In the vertical case CBN 91 is predicted to be unstable from 43 ° to 47 °C (figure 5).
Overlapping the three pictures we see that, for cavity ANKA_1, temperature settings between 47 °C and 54 °C or between 62 °C and 69 °C should avoid any excitation of coupled bunch oscillations in ANKA.

5 CONCLUSION

Stable operating conditions are predicted for cavity ANKA_1 on the base of the measured HOM data. They will be confirmed after checking the HOM spectrum after in situ installation of the cavity.
All other ANKA Storage Ring cavities will be characterised in the same way and the complete prediction of stable operating intervals will be available.

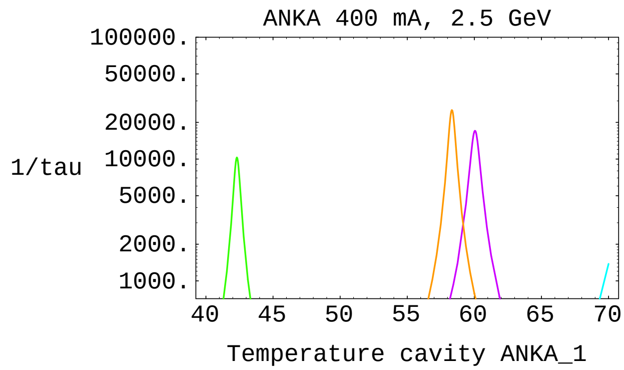

Fig. 3: Longitudinal CB growth rates vs. temperature

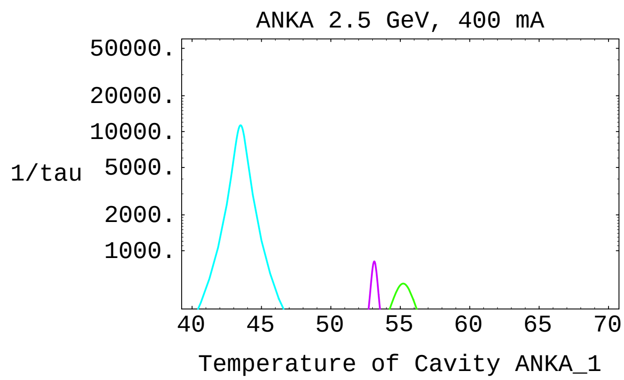

Fig. 4: Transv. horizontal growth rates vs. temperature

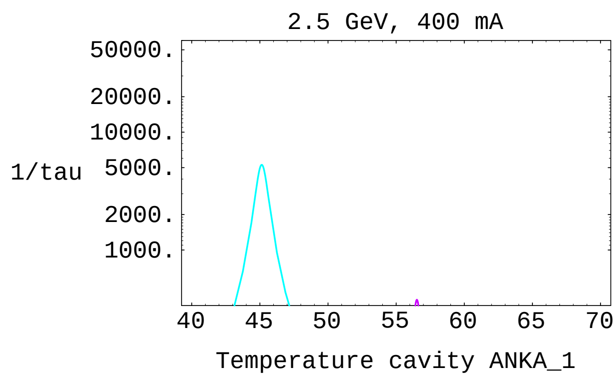

Fig. 5: Transv. vertical growth rates vs. temperature

6 REFERENCES

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