CHARACTERISATION OF THE EU-HOM-DAMPED NORMAL CONDUCTING 500 MHz CAVITY FROM THE BEAM POWER SPECTRUM AT DELTA*

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Abstract

A HOM-damped prototype cavity (EU-cavity) [1] developed in the framework of an EC collaboration has been installed into the Dortmund synchrotron light source DELTA. This paper reports on beam studies performed at beam energies of 1.5 GeV and 542 MeV in an attempt to get information on coupled bunch instability (CBI) thresholds. In addition an evaluation of the longitudinal cavity impedance is presented, based on beam power spectra up to 3 GHz for different filling patterns of the storage ring by analysing the RF signal from the HOM-dampers.

CBI THEORY

The electric field components of a cavity's higher order modes (HOM), which are excited by the particle beam itself, while passing the resonator, couple bunch motion to collective so-called coupled bunch modes (CBM). These modes are discribed by the model of linear coupled rigid oscillators, having the same eigenfrequencies [2]. For n oscillators the number of modes existing is also n. Each mode is characterised by its phase advance between oscillators, which is $\varphi_k = \frac{2\pi}{n}k$, with $k = [0, n-1]$ indicating the mode.

Observing a longitudinal motion at a fixed position, the frequency $f_{p,k}$ of a mode is given by:

$$f_{p,k} = (pn + k + Q_s) f_0, \tag{1}$$

where f_0 is the revolution frequency, Q_s the synchrotune and pn with $p = [-\infty, \infty]$ redisplaying the circular character of the problem.

The particle's oscillation is mainly damped by emission of synchrotron radiation, while its excitation is due to the HOM impedance[1] $R_\parallel(f)$. For a CBI to rise, two conditions have to be fulfilled:

- excitation from the impedance is stronger than radiation damping
- just like for Robinson instability, $f_{p,k}$ is on the inductive slope of the HOM-impedance

A threshold impedance for CBM k to be unstable at a certain stored current can be deduced [2], which is:

$$R_\parallel(f_{p,k}) = \frac{2EQ_s}{\tau_\epsilon e \eta} \frac{1}{f_{p,k} I_b(f_{p,k})}, \tag{2}$$

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[1] For an easier description common literature represents a HOM by an impedance, rather than by it's electric field.

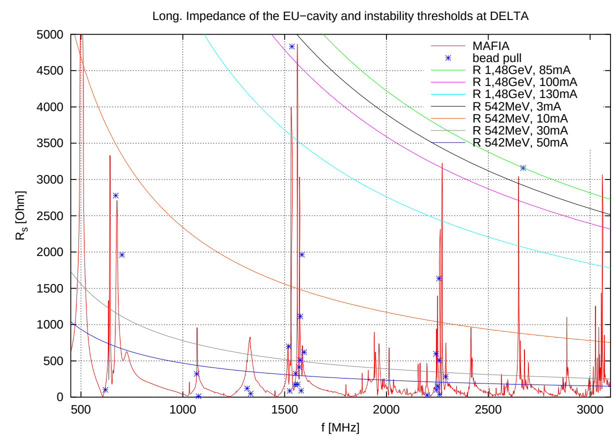

Figure 1: Computed and measured longitudinal impedances of the HOM-damped EU-cavity [1] together with threshold impedances of DELTA at several currents and energies.

with the beam energy E, τ_ϵ the longitudinal damping time, e is the elementary charge, η the momentum-compaction and $I_b(f_{p,k})$ the fourier component of the stored beam current at $f_{p,k}$.

CBM MEASUREMENT

The goal of the actual measurements was to compare the performance of the EU-cavity with an undamped DORIS single cell cavity, whose CBM behaviour was presented in [3]. The experimental setup, together with a set of DELTA beam parameters was shown there, the measurement algorithm has been adopted from [4]. Different from the DORIS cavity tests, where the cavity body temperature was varied between 35 and $60\,^\circ\mathrm{C}$, the temperature now was kept constant, due to the large bandwidths of damped HOMs, which are of the order of several MHz (see fig.1). As a change in temperature of some degrees will not result in a significant change of impedance, the influence on instability thresholds is negligible.

Measurements have been performed at beam energies of $1.5\,\mathrm{GeV}$ and $542\,\mathrm{MeV}$ with different stored beam currents up to $120-130\,\mathrm{mA}$ at $1.5\,\mathrm{GeV}$, $160\,\mathrm{mA}$ at $542\,\mathrm{MeV}$ respectively with a filling pattern of 144 out of 192 buckets consecutively filled. The filling pattern was monitored during CBM scans with the setup presented in [5]. The RF standard settings, which were applied during the experi-

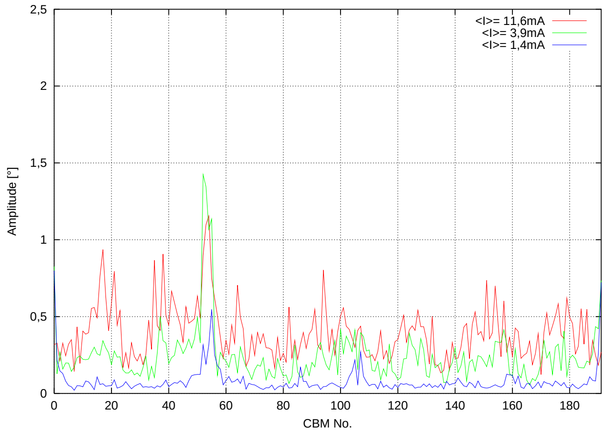

Figure 2: CBM spectra at $542\,\mathrm{MeV}$ and mean beam currents of $11.6\,\mathrm{mA}$ (red) $3.9\,\mathrm{mA}$ (green) $1.4\,\mathrm{mA}$ (blue), taken with the EU-cavity installed.

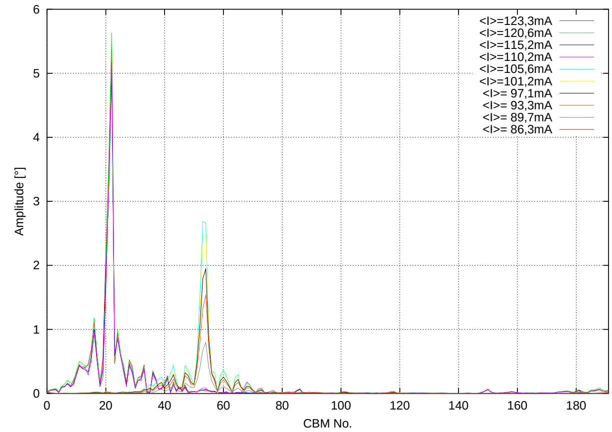

Figure 3: CBM spectra at $1.5\,\mathrm{GeV}$ and mean currents between 123.3 and $86.3\,\mathrm{mA}$ (top to bottom in legend) with the EU-cavity

ments, are listed in table 1.

Table 1: List of DELTA's standard RF- and synchrotron frequency at an energy of $542\,\mathrm{MeV}$ and $1.5\,\mathrm{GeV}$ respectively

E [MeV]	f_{RF} [MHz]	f_s [kHz]
542	499.830	25.5
1484	499.819	15.3

As with the undamped DORIS-cavity, the EU-cavity measurements showed a strong broadband excitation of the beam covering all CBMs at low energy and currents above $15\,\mathrm{mA}$. Therefore it was not possible to identify any CBM structure for a high current beam, because the beam was well above instability threshold. With current decaying below $15\,\mathrm{mA}$ a single CBM band 53-55 evolved from the spectra and remained until detection limit, which is about $1\,\mathrm{mA}$ (see fig.2). At high energy CBM 53-55 was also found (fig. 3), but with a current threshold of $89 - 90\,\mathrm{mA}$. The only HOM with a resonance frequency corresponding to CBM 53-55 is at $642\,\mathrm{MHz}$, but its shunt impedance is far below threshold of at least $11.8\,\mathrm{k\Omega}$ for instability (see table 2). The strongest mode impedance at all is (from fig.1) $4.9\,\mathrm{k\Omega}$ at $1.562\,\mathrm{GHz}$. Modifying the RF-frequency and power to change the CBM frequency w.r.t. the driving impedance resulted in a change of threshold current (table 2), indicating that the change of impedance with frequency is in the order of $\mathrm{k\Omega/kHz}$ and therefore the origin is of narrowband behaviour. These two facts imply that CBM 53-55 is most probably not cavity driven.

If beam accumulation was pushed above DELTA's nominal current of $120\,\mathrm{mA}$, CBM 21-22 was rising. Between currents of $105 - 110\,\mathrm{mA}$ this mode decays and the beam switches back to CBM 53-55 and remains in this mode until threshold (see fig.3).

Both modes have also been discovered with a damped DORIS-cavity installed into the DELTA storage ring for a short period of time (see fig.4). The behaviour was comparable, which implies that those CBMs observed are neither driven by the HOM-damped EU-cavity, nor by the DORIS-cavity. Cavity induced instabilites may be masked by this excitation, investigations to identify the driving impedance are ongoing.

IMPEDANCE MEASUREMENTS

The circular waveguide to coaxial transitions (CWCT), which serve as HOM-dampers for the EU-cavity are designed to couple broadband to all HOMs of the resonator (see [1]). The HOM-energy is dissipated in external 50Ω-loads, that are connected to the N-port of the CWCT. If a spectrum analyser (R&S FSP3, 9kHz-3GHz) is attached to this port instead of a load, one is able to obtain full mode spectra during beam operations, without being limited by a coupling loop's directivity. As the cavity also works as a pick-up in this setup, the spectra obtained are a convolution of the (driven) HOM-spectrum and the beam power spectrum. From this one should be able to get a quantitative knowledge of the impedance via $U(\omega) = R_{\|}(\omega)I_b(\omega)$, if the beam spectrum is known. The induced voltage $U(\omega)$ is measured, the longitudinal cavity impedance $R_{\|}(\omega)$ is received from $I_b(\omega)$, a computed fourier-transform of the

Table 2: Threshold current dependance of CBM 55 on RF- and synchrotron frequency at $1.5\,\mathrm{GeV}$ with EU-cavity and resulting impedances for $f_{p,k} \approx 640.4\,\mathrm{MHz}$ assumed.

f_{RF} [MHz]	f_s [kHz]	I_{th} [mA]	$R_{\mathrm{th}}(f_{p,k})$ [kΩ]
499.819	13.9	105	11.8
499.819	15.3	89	13.9
499.824	15.4	55	22.4

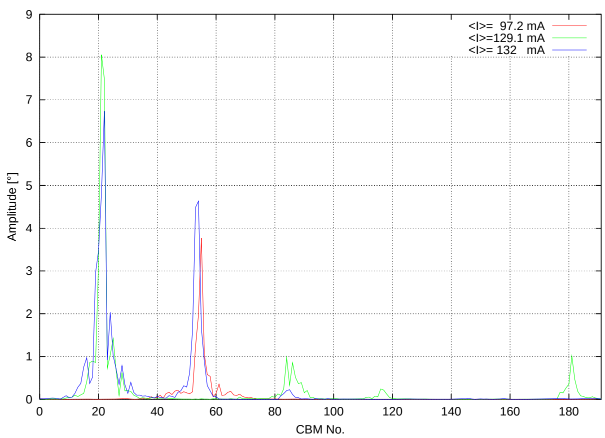

Figure 4: CBM spectra of a damped DORIS-cavity at $1.5\,\mathrm{GeV}$ and mean currents of 97 (red), 129 (green) and $132\,\mathrm{mA}$ (blue), also with this resonator CBM 21-22 and 53-55 is appearing.

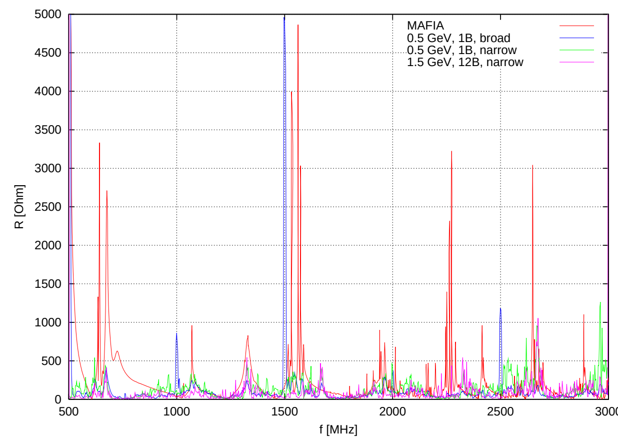

Figure 5: Impedance spectra of the EU-cavity at single-bunch operations from narrow- and broadband measurements and 12-bunch narrowband compared to MAFIA results.

circulating beam (see [3] for algorithm) with the actual filling structure [5].

Spectra, filling pattern, beam current and the transmission line's insertion loss between CWCT and analyser for amplitude correction of the spectra are input to the simulation program. It computes the beams time domain function, performs a FFT and calculates $R_{\|}(\omega)$. The computed beam spectra are current-calibrated to get $I_b(\omega)$.

Two measurement procedures have been carried out: one is to measure narrowband (bandwidth $1\,\mathrm{kHz}$) the amplitude of each revolution harmonic from $500\,\mathrm{MHz}$ to $3\,\mathrm{GHz}$, the other is to collect a broadband spectrum $500\,\mathrm{MHz}$ to $3\,\mathrm{GHz}$ with $10\,\mathrm{MHz}$ bandwidth from the analyser. Spectra were recorded at both energies, with 144, 12 and single-bunch pattern (single-bunch @ $1.5\,\mathrm{GeV}$ not yet possible). By measuring only harmonics no dynamic influences, like excited sidebands which might spoil the results, are included and a lower noise basis is achieved. On the other hand broadband spectra are fast to acquire and therefore no lifetime effects have to be considered.

The measured mode frequencies up to about $1.5\,\mathrm{GHz}$ agree qualitatively well with the calculations. The more narrowband modes above $1.5\,\mathrm{GHz}$ are not reproduced that well. A reason may be HOM shifting from the plunger position. $542\,\mathrm{MeV}$ single- and $1.5\,\mathrm{GeV}$ 12-bunch operations (fig. 5) gave the best results. A 144-pattern returns a bad S/N-ratio because of an extensive cancellation of frequencies. Single-bunch broadband spectra reproduce low frequency $R_{\|}$ smoother, but also the RF harmonics are quite strong there. Measured beam spectra show a significant offset to the calculated ones, so the impedance spectra in fig. 5 have been multiplied by a resulting factor. This shows, that our current-calibration is not yet sufficient and we have to look for a more elaborate way of calibrating our spectra, to eliminate this offset.

CONCLUSION

The HOM-damped EU-cavity has been characterised in the DELTA storage ring at two beam energies with different currents stored. In the vicinity of strong non-cavity excitations no HOM driven CBM could be detected. Investigations to find the origin of these excitations are ongoing. Hereafter the characterisation has to be repeated. Furthermore the HOM-spectrum of the cavity was measured from the RF-signal of a HOM-damper port by unfolding it with a calculated beam power spectrum of the known actual filling structure. Results of this procedure are encouraging, but some more effort has to be put into a proper current calibration of the calculated beam spectra.

ACKNOWLEDGMENTS

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