

# BEAM PHYSICS ISSUES IN CANDLE SYNCHROTRON LIGHT SOURCE PROJECT\*

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**Abstract**

CANDLE- Center for the Advancement of Natural Discoveries using Light Emission - is a 3 GeV synchrotron light source project in Republic of Armenia. The summary of the facility beam physics study is given, including the optimal beta performance in insertion devices, dynamical aperture, the machine broadband impedances, coupled bunch instabilities, ion trapping and beam lifetime.

## INTRODUCTION

The beam physics issues are one of the most important parts of the synchrotron light sources design study that define the quality and stability of electron and photon beams. One of the features of CANDLE project [1] design study was the optimisation of the facility performance based on the achievement of a high brightness photon beams from insertion devices and the stable stored electron beam by means of the dynamical aperture of the ring [2]. The second stage of the beam physics activity included the ring broadband impedance study [3-5], evaluation of the coupled bunch instability, ion trapping and beam lifetime [6].

## OPTICS AND DYNAMIC APERTURE

The CANDLE design has 16 identical DBA type cells with non-zero horizontal dispersion in the middle of the straight section  $\eta_x = 0.18m$  that provides 8.4 nm-rad horizontal emittance of the beam. The spectral brightness of the photon beam from undulators is one of the main figures of merits that define the advance of the facility design to utilize the whole capacity of the insertion devices. The optimisation of the optical parameters of the lattice to obtain a high spectral brightness of the photon beams keeping large the dynamical aperture of the ring has been performed [2].

Fig.1 shows the dependence of the normalized brightness on the emitted photon energy for different horizontal and vertical beta values at the source point. Dashed line corresponds to the optimal beta values associated with each photon energy. The improvement of the brightness with small horizontal beta is visible only for the photon energies below 0.1 keV. Starting from 0.5 keV the brightness increases with larger betatron function, and in the energy range of higher than 5 keV the brightness reaches its maximum for the 8 m of beta value.

In vertical plane the beam emittance is given by the coupling of the horizontal and vertical oscillations. The small vertical emittance of the beam shifts the

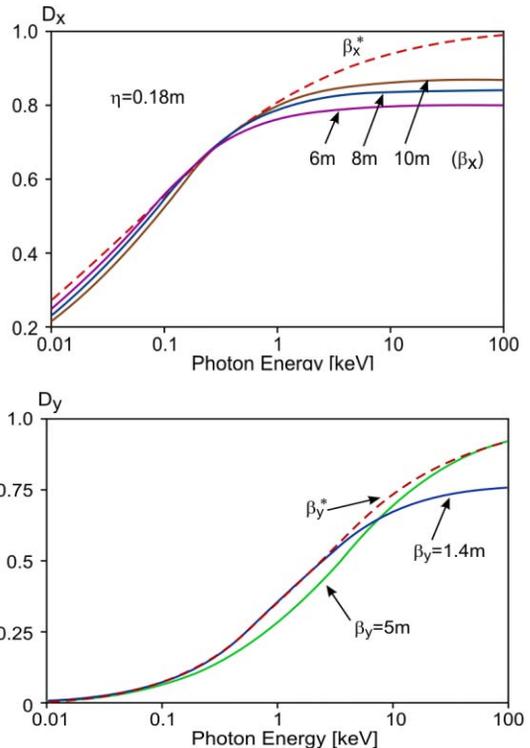


Figure 1: The normalized CANDLE brightness versus photon energy for various horizontal and vertical beta.

characteristic regions of the brightness behaviour to harder X-ray region. The increasing of the spectral brightness with low beta is now visible in the photons energy range of 0.5-8 keV and starting from about 10 keV the brightness increases for high beta function.

The horizontal and vertical betatron functions in the middle of the straight sections are optimized to  $\beta_x = 8.1m$ ,  $\beta_y = 4.85m$ . Fig.2 shows the CANDLE storage ring dynamic aperture with 3% energy spread which is sufficient for facility stable operation.

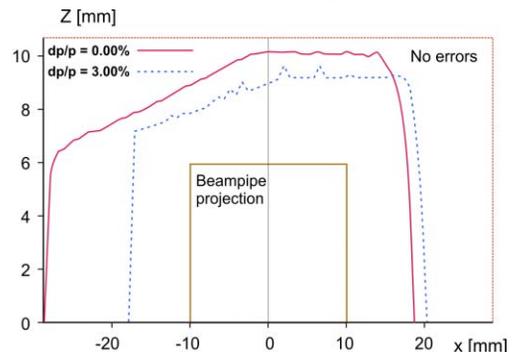


Figure 2: The storage ring dynamic aperture (ID).

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### BROADBAND IMPEDANCE

To prevent the single bunch instabilities in the ring, the impedance caused by the walls resistivity and roughness, BPM's and transitions has been studied. Fig. 3 presents the longitudinal and transverse impedances of the storage ring for various distributed impedance sources.

The normalized longitudinal broadband impedance for the CANDLE storage ring without ID's is at the level of 0.35 Ω. The corresponding single bunch threshold current is 8.9 mA. The transverse impedance of the ring without ID's is 12.6 kΩ/m that defines the threshold current of 113 mA for the transverse single bunch instability. The CANDLE nominal operation current of 350mA implies the single bunch current of 1.24 mA that is far below of the threshold currents.

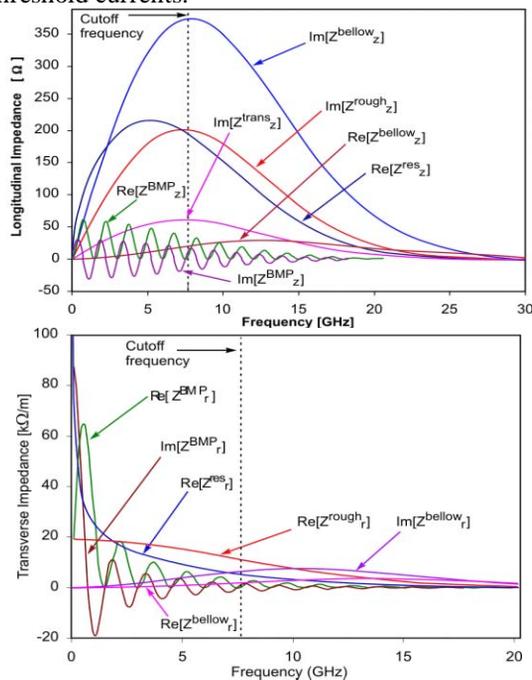


Figure 3: Longitudinal and transverse impedances of the ring caused by the walls resistivity, roughness, BPM's and transitions.

An additional contribution to the ring impedance will be dominated by the small gap undulator vacuum chamber installed in the straight section of the ring.

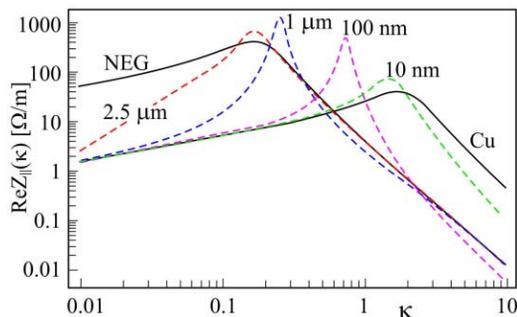


Figure 4: Real part of copper-NEG tube longitudinal impedance for various cover thickness.

To reduce the resistive impedance of the chamber the laminated walls are usually used, i.e the copper chamber covered by the NEG (Non-Evaporated Getter). Fig. 4 presents the real part of the point charge longitudinal impedance [4] for the cooper-NEG, 5 mm aperture vacuum chamber. The evaluation of the transverse impedance of laminated vacuum chamber is given in [5].

### COUPLED BUNCH INSTABILITIES

The narrow band impedance of the storage ring, basically the longitudinal and transverse High Order Modes (HOM) excited by beam in the RF cavities, determine the longitudinal and transverse multi-bunch instabilities.

The longitudinal and transverse coupled bunch instabilities for the CANDLE storage ring have been studied for the original ELETTRA cavity option. Fig. 5 presents the growing rate of longitudinal and transverse coupled bunch instabilities versus the relative mode index *n* for the 282 beam oscillation modes.

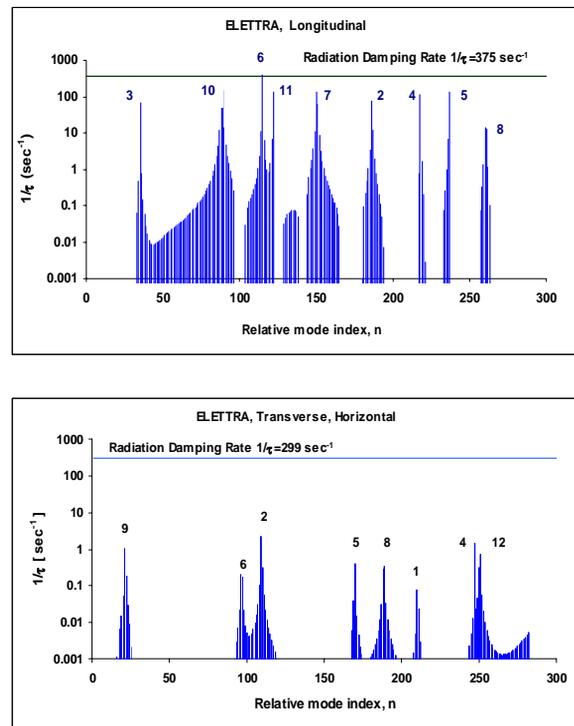


Figure 5: The longitudinal and transverse coupled bunch instabilities growing rate versus beam oscillation modes.

The growing rates of instabilities are mostly below the synchrotron radiation damping coefficients, except for L6 longitudinal mode that excites the instability at relative oscillation mode of *n*=115. After the cavities RF measurements, the instability cures will be developed to ensure the stable operation of the facility.

### ION TRAPPING

To prevent the reduction of the beam lifetime due to ion trapping, the stability of the transverse motion of the ions

has been checked along the regular lattice of the storage ring. The results are presented in Fig. 6.

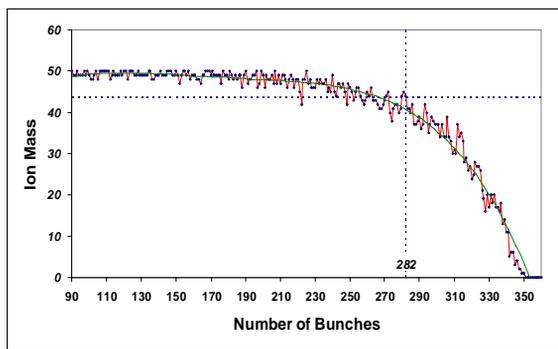


Figure 6: Number of unstable ions versus number of bunches in the ring.

The effect of the ion trapping is observed when the number of bunches in the ring exceeds 90. The optimal value of the number of bunches for the CANDLE storage ring has been defined  $h_b = 282$  which provides an ion-cleaning gap of 78 RF buckets not filled with the electrons. With such a cleaning gap, only 6 ions number are trapped. An additional criterion for the optimisation of the number of bunches in multi-bunch operation mode is an analysis and comparison of the list of trapped ions with the mass numbers of real residual gas species.

The trapped ion mass numbers in CANDLE storage ring are given in Table 1; the number of bunches is 282. The comparison with species of the ions in the residual gas that can occur in the chamber shows that for the given number of bunches 282 no components of residual gas will lead to trapped ions in the ring. The chosen number of bunches in the storage ring, 282 bunches from available 360 RF buckets, provides practically trapped ions-free operation of the machine at almost 80% filling.

Table 1: Trapped ion masses and residual gas species

Trapped ion masses	Residual gas species
-	2, H <sub>2</sub>
-	16, CH <sub>4</sub>
17	-
-	28, N <sub>2</sub> , CO
32	-
33	-
37	-
42	-
-	44, CO <sub>2</sub>
48	-

### BEAM LIFETIME

Beam lifetime in the storage ring is dominated by three beam loss-processes: the quantum excitation, intra-beam scattering (Touschek effect), and scattering off of residual gas molecules (elastic and inelastic). The Touschek lifetime is the most critical one. Fig.7 shows the Touschek lifetime evolution along the lattice for various energy

acceptances. For a circulating current of  $I = 350$  mA, the charge per bunch is 0.9 nC assuming 282 RF buckets of the total 360 are filled. For an energy of 3 GeV and RF energy acceptance of 2.38%, the average Touschek lifetime over the ring is then about 39 hours.

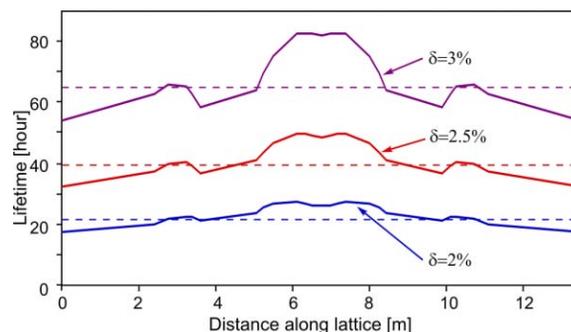


Figure 7: Touschek lifetime evolution along the lattice for various energy acceptances (solid lines).

In particular, for a coupling of 2% and energy acceptance of 2.4% the Touschek lifetime is at level of 54 hours. An integrated beam lifetime in storage ring is at the level of 18.4 hours.

### SUMMARY

The results of the beam physics study for the CANDLE synchrotron light source project is summarized. For the CANDLE parameters it is shown that the focusing lattice with high beta value in the middle of the straight section is preferable to obtain a high spectral brightness of the photon beams with relatively large dynamical aperture of the ring.

Among with the study of the machine broadband impedance, coupled bunch instability, ion trapping and beam lifetime, the analytical presentations of the longitudinal and transverse impedances of small gap undulator laminated vacuum chamber have been obtained. The results of this report can be useful for the design, optimisation and beam physics study of new synchrotron light source projects.

### REFERENCES

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