A PROPOSED RF SYSTEM FOR THE LSB STORAGE RING

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Abstract

The RF system in a storage ring should replace the energy lost by the electrons as synchrotron radiation and it should provide enough energy acceptance in order to have large quantum and Touschek lifetimes. Lifetimes, bunch length and single bunch instabilities are analysed in order to determine the total voltage that the RF system should provide to the 250 mA electron beam. The RF system will work at 500 MHz. The type of cavity used and the number necessary to fulfil the power requirements of the machine will be presented. Finally the RF parameters for the multibunch and singlebunch operation modes are given.

1. INTRODUCTION

Parameters that depend on the RF voltage are analysed in this paper for the LSB storage ring [1], that has a TBA lattice structure composed of 12 cells and with a total circumference of 251.84 m. The natural emittance has been minimised to 8.3 nmrad at 2.5 GeV, the nominal energy. Table 1 gives the main parameters.

Table 1. Storage Ring parameters

Nominal energy	[GeV]	2.5
Circumference	[m]	251.84
Natural Emittance at 2.5 GeV	[nm rad]	8.3
Coupling	[%]	5
Revolution frequency	[MHz]	1.19
RF frequency	[MHz]	500
Harmonic number		420
Momentum compaction factor		0.00194
Energy spread		$8.6\ 10^{-4}$
Number of bendings		36
Max. Magnetic field	[T]	1.01

The design goal is to store a beam of 250 mA for about 24 hours.

The synchrotron radiation losses due to insertion devices have been estimated by considering that 11 straight sections will be used with the following magnets: 2 SC Wigglers at 6 T, 3 Wigglers at 2 T, 3 Wigglers at 1.5 T and 3 Wigglers at 1 T. The total loss and the required power to be provided to the beam are given in table 2.

Table 2. Power losses

Bending losses	[keV/turn]	418
Insertion Devices losses	[keV/turn]	239
Total loss	[keV/turn]	657
Beam Intensity	[mA]	250
Power to beam	[kW]	165

2. RF CAVITY

By looking at the newest Synchrotron Light Sources and at the existing commercial products, it has been decided to work at a RF frequency of 500 MHz. The main advantage over lower frequencies comes from the reduction of bunch length that gives better light performances.

Nose-cone and bell-shaped cavities have been analysed in an internal report [2]. Quality factor, shunt impedance and high order modes were calculated for both cavities. Small differences between these parameters were found. The bell shaped cavity has a 20% lower shunt impedance at the fundamental mode than the nose-cone one. Both cavities will give problems with multibunch instabilities [2]. However, bell-shaped cavities give less problems with multipactoring and sparking effects.

We have chosen a bell shaped cavity because a 20% higher shunt impedance does not means an important saving of power for the LSB. Also because in order to avoid multibunch instabilities the temperature will have to be controlled within ±0.1ºC and this is easier to do in a bell shaped cavity. Finally, it should also be noticed that the manufacturing of the bell shaped cavity is easier and consequently cheaper than the nose-cone cavity.

Figure 1 shows the basic geometry of the cavity and table 3 gives the parameters for the fundamental mode.

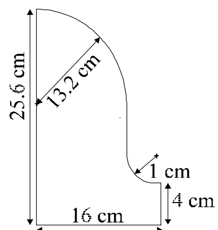

Figure 1. Bell cavity section

Table 3. Fundamental mode parameters

Frequency	[MHz]	500
Impedance, Z	[MΩ/m]	20.8
Quality factor, Q		43900
Transit time factor, T		0.67
$R_s^0 = LZT^2$	[MΩ]	4.00
$R_s = 0.85\ R_s^0$	[MΩ]	3.40

The calculated shunt impedance (R_s^0) given in the previous table has to be reduced around a 15% of its value in order to take into account that the actual cavity will have extra ports for feeding, tuning and testing. Therefore in subsequent calculations we will take for the shunt impedance a more realistic value of $R_s = 3.4$ MΩ.

3. MULTIBUNCH OPERATION

The goal of this operation mode is to store 250 mA into the storage ring. Three different possibilities will be considered:

- *Full filled.* Fill all the RF buckets of the storage ring. That is 420 bunches with 0.6 mA each.
- *30% gapped.* Fill 70% of the machine with contiguous buckets. That is 294 bunches with 0.9 mA each, leaving 250 ns to clear ions.
- *50% filled.* Fill 50% of the machine, one each two buckets. That is 210 bunches with 1.2 mA each.

The code ZAP [3] has been used to calculate the intensity threshold due to microwave instabilities. The calculation has been performed for different RF applied voltages, figure 2 shows the results.

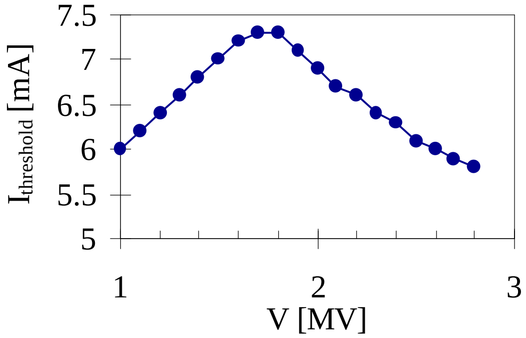

Figure 2 Bunch current threshold as a function of voltage.

For these calculations a vacuum pipe impedance of 2 Ω has been assumed. The equivalent broadband impedance of the cavities has been calculated with ZAP, and it is 0.030 Ω/cavity for the bell cavity. The SPEAR scaling has been applied to short bunches.

The threshold intensity for voltages between 1 and 3 MV is greater than 5 mA per bunch. For the three multibunch mode operations considered, the intensity per bunch is lower than this threshold value. That indicates that microwave instabilities will not affect the beam.

At the energy of 2.5 GeV, quantum lifetime is not a limiting parameter. In all cases considered in this paper it is larger than 1000 h. The Touschek lifetime has to be greater than 48 h in order to obtain a total lifetime around 24 h [4].

The Touschek lifetime depends strongly on the applied voltage and on the bunch current. Figure 3 shows its dependence on RF voltage for the three modes of operation.

We have now all the arguments to define the more convenient RF parameters for each operation mode, see table 4.

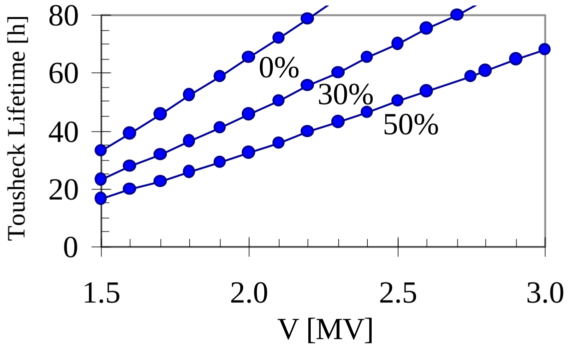

Figure 3. Touschek lifetime as a function of RF voltage for the three multibunch modes.

Table 4. Multibunch operation modes

			Full	30%	50%
Effective voltage	V_{eff}	[MV]	1.8	2.2	2.6
Overvoltage factor	q		2.7	3.3	4.0
RF acceptance	ε_{RF}	%	1.7	2.0	2.3
Beam intensity	I	[mA]	250	250	250
Number of bunches	k		420	294	210
Current per bunch	I_b	[mA]	0.6	0.9	1.2
e^- per bunch	N	[10^9]	3.1	4.5	6.2
Bunch length	σ_l	[mm]	7.2	6.4	5.9
		[ps]	24.0	21.4	19.6
Touschek lifetime	τ_t	[h]	52	55	53

4. RF POWER SYSTEM

The optimum RF system has to be found by minimising: the number of cavities, the RF power and the instabilities; and by fulfilling the following requirements: to replace the energy lost by synchrotron radiation, to obtain a Touschek lifetime larger than 48 h and to obtain the necessary energy acceptance.

From table 4 it appears that the RF system has to be able to give 2.6 MV.

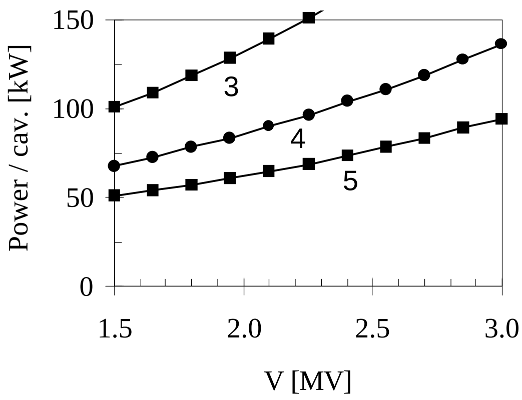

Figure 4. Power per cavity as a function voltage and number of cavities, for 250 mA beam.

Figure 4 shows the power per cavity as a function of RF voltage and for different number of cavities in the storage ring, for a beam current of 250 mA.

Let us consider that each cavity will have only one loop window, and that there is a limitation of 150 kW of power per window. Moreover, let us consider 20% of power losses due to energy transport and to imperfect coupling. Four cavities are therefore necessary to cover the range of voltage required.

The RF power system will be formed by four modules, each one with one cavity fed with a 150 kW klystron. The maximum voltage for a beam of 250 mA will be 2.7 MV. Figure 5 shows the proposed configuration.

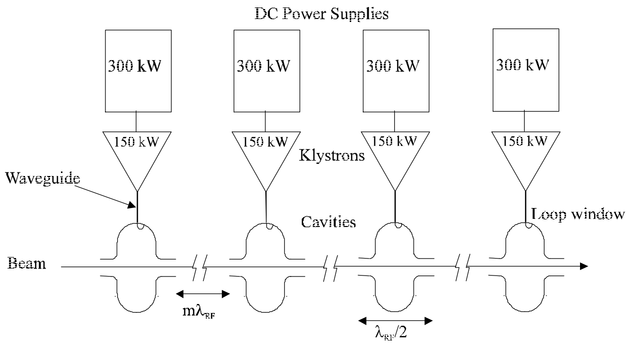

Figure 5. RF power system

The cavities are located in different straight sections around the machine. The power needed to maintain the beam is given by table 5.

Table 5. Power requirements for 250 mA beam

			Full	30%	50%
Effective voltage	V_{eff}	[MV]	1.8	2.2	2.6
Overvoltage factor	q		2.7	3.3	4.0
Synchrotron phase	ϕ	[rad]	0.37	0.30	0.25
Nº Cavities			4	4	4
Effec. voltage/cav.	V_{cav}	[MV]	0.45	0.55	0.65
Power to beam/cav.	P_{beam}	[kW]	41	41	41
Power dissipated/cav.	$P_{diss.}$	[kW]	30	45	62
Other loss [10%]	P_{others}	[kW]	7	9	10
Total power/cav.	P_{cavity}	[kW]	78	94	114
Total power	P_{total}	[kW]	312	376	454

5. SINGLEBUNCH OPERATION

To find the possible singlebunch operation modes, we will use the total power given by the RF configuration defined earlier, which allows a voltage of 3.4 MV for a maximum beam intensity of 20 mA.

The aim of the singlebunch operation is to have a single bunch into the storage ring with the highest possible intensity and the smallest bunch length. Microwave instabilities and potential well distortion will play an important role in this case. Calculations have been done with ZAP code for the applied voltage of 3.4 MV. Due to these instabilities, for each bunch current, the bunch length will grow up to a new equilibrium value, see figure 6.

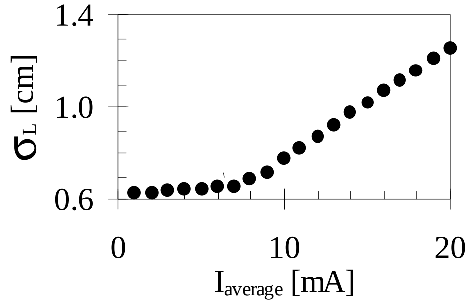

Figure 6. Bunch lengthening for 3.4 MV

This new value is used to calculate the Touschek lifetime. Table 6 gives three possible singlebunch operation modes.

Table 6. Singlebunch operation modes

Effective voltage	V_{eff}	[MV]		3.4	
Overvoltage factor	q			5.2	
RF acceptance	ε_{RF}	%		2.8	
Beam intensity	I	[mA]	5	10	20
Number of bunches	k		1	1	1
Current per bunch	I_b	[mA]	5	10	20
e^- per bunch	N	$[10^{10}]$	2.6	5.2	10.4
Bunch length	σ_l	[mm]	5.3	6.5	9.6
		[ps]	18	22	32
Touschek lifetime	τ_t	[h]	18	11	8

Good singlebunch operation modes with lifetime around 10 h can be achieved with the defined RF configuration. Users necessities of time resolution will finally determine the best singlebunch mode to be used.

6. CONCLUSION

A RF system has been defined for the LSB storage ring. Four modules each with 1 cavity fed with a klystron of 150 kW through one window give good performances for both the multi- and the singlebunch operation modes.

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