PROPOSAL OF A STRONG RF FOCUSING EXPERIMENT AT DAΦNE

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Abstract

The strong RF focusing is a recently proposed technique to obtain short bunches at the interaction point in the next generation colliders. A large momentum compaction factor together with a very high RF gradient across the bunch provide a modulation of the bunch length along the ring, which can be minimized at the Interaction Point (IP). No storage ring has been so far operated in such a regime, since it requires uncommonly high synchrotron tune values. In this paper we present the proposal of creating the experimental conditions to study the strong RF focusing in DAΦNE. The proposed machine lattice providing the required high momentum compaction value, the upgrade of the RF system including the installation of a multi-cell superconducting cavity, the upgrade of the cryogenic plant and a list of the possible beam experiments are illustrated and discussed.

INTRODUCTION

The required luminosity for the next generation "factory" colliders is from 1 to 2 orders of magnitude higher with respect to the present performances [1].

In flat beam colliders the luminosity can be increased by reducing the vertical beta-function at IP β_y to further squeeze the vertical beam size and decrease the effect of beam-beam interaction. This approach is effective only if the bunch length σ_z does not exceed the β_y value and the "hourglass" effect is avoided [2]. Bunch lengths of the order of 1 mm are needed, and this is very difficult to achieve with standard techniques.

Recently [3] a novel approach called Strong RF Focusing (SRFF) has been proposed to overcome this difficulty. It consists in combining highly dispersive lattices (providing momentum compaction factors α_c about 1 order of magnitude larger than usual) with very high RF voltages. This results in a regime where the bunch length is modulated along the ring, showing a maximum in the region around the RF section. Taking the position of the RF cavity as the origin $s = 0$ of the longitudinal reference frame, one gets:

$$\sigma_z(s) = \frac{\sigma_E}{E}\alpha_c L\sqrt{\frac{1}{2}\frac{1}{1-\cos\mu} - \frac{R_{56}(s)}{\alpha_c L}\left(1-\frac{R_{56}(s)}{\alpha_c L}\right)} \quad (1)$$

where L is the ring length, σ_E/E is the bunch relative energy spread, $R_{56}(s)$ is the path elongation from 0 to s normalized to the particle relative energy deviation, and μ is the one-turn synchrotron phase advance given by:

$$\cos\mu = 1 - \pi\frac{\alpha_c L}{\lambda_{RF}}\frac{V_{RF}}{E/e} \quad (2)$$

According to (1), the bunch is shortest at the azimuth $s_{\min}$ where $R_{56}(s_{\min}) = \alpha_c L/2$. If the ring design is such that $s_{\min}$ corresponds to the IP, one gets:

$$\frac{\sigma_z(IP)}{\sigma_z(RF)} = \sqrt{1-\frac{\pi}{2}\frac{\alpha_c L}{\lambda_{RF}}\frac{V_{RF}}{E/e}} = \sqrt{\frac{1+\cos\mu}{2}} \quad (3)$$

For μ values close to π the ratio between minimum and maximum bunch lengths can be very low. To correctly compute the bunch length values by means of (1) it must be noticed that the equilibrium energy spread σ_E/E in the SRFF regime is magnified by a factor G with respect to the unperturbed value $(\sigma_E/E)_0$, with G given by:

$$G^2 = \frac{\oint\left[1-(1-\cos\mu)\frac{2R_{56}(s)}{\alpha_c L}\left(1-\frac{R_{56}(s)}{\alpha_c L}\right)\right]\frac{ds}{|\rho(s)|^3}}{\oint\frac{ds}{|\rho(s)|^3}} \quad (4)$$

where $\rho(s)$ is the local bending radius.

The potentiality of the SRFF scheme is quite evident. It allows designing a collider where the bunch is extremely short at the IP and reasonably long elsewhere, especially near the RF cavities. Synchrotron light source can also benefit this scheme for time resolved experiments.

However, this idea has not been experimentally tested yet since none of the storage rings presently in operation can be pushed into this regime unless significant modifications in the lattices and/or in the RF systems are implemented. We are proposing to temporarily modify both the DAΦNE lattice and RF system to make the first experimental observation and measurement of the bunch length modulation obtained with the SRFF scheme.

A SRFF EXPERIMENT AT DAΦNE

The Φ-factory DAΦNE is a double ring e^+e^- collider working at the Φ resonance (1.02 GeV in the center of mass) in operation since 1999 at the Frascati National

Labs of INFN [4]. A design study for a substantial upgrade of DAΦNE aimed at increasing the luminosity by about 2 orders of magnitude is in progress [5] and relies mainly on the implementation of the SRFF scheme. An experimental proof of the feasibility of such a scheme is necessary to validate our approach to the luminosity upgrade and represents an important contribution to any other future project requiring very short bunches.

A list of the possible SRFF experimental activities that can be covered at DAΦNE includes:

- Measuring the bunch length variation along the ring;
- Study the single bunch dynamics (effects of the distributed wake on the bunch length);
- Study the multibunch dynamics and the behaviour of the bunch-by bunch feedback system at very large synchrotron tunes;
- Study of the 3D coupled dynamics;
- Collisions of short bunches (with $\beta_y \leq 1cm$);
- Study of the Coherent Synchrotron Radiation (CSR).

The goal is to demonstrate the SRFF effectiveness in various configurations, approaching as much as possible the operating conditions of a high luminosity collider: low current in a single bunch ($I < 1mA$), high current in a single bunch ($I \approx 10mA$, to study the bunch lengthening process), high current in multibunch regime ($I \approx 0.5A$ in 60 bunches). The DAΦNE parameters for the SRFF experiment are reported in Table 1.

Table 1: DAΦNE parameters for the SRFF experiment.

Momentum Compaction	α_c	0.08
RF Frequency	f_{RF}	1288.973 MHz
RF Voltage	V_{RF}	7 MV
Harmonic Number	h	420 (= 3.5 x 120)
Long. Phase Advance	μ	$2\pi/3$
Natural Energy Spread	$(\sigma_E/E)_0$	$4 \cdot 10^{-4}$
Energy Spread @ $\mu = 2\pi/3$	σ_E/E	$6 \cdot 10^{-4}$
Bunch Length	σ_z	1.3 - 2.5 mm
RF Acceptance (IP/RF)	$(\Delta E/E)_{max}$	$7 \cdot 10^{-3} / 5 \cdot 10^{-3}$

According to (3), a one-turn longitudinal phase advance $\mu \geq 2\pi/3$ is required to produce a bunch length variation of about a factor 2 or larger. A 50 % increase of the bunch energy spread is expected.

LATTICE DESIGN

The DAΦNE layout is shown in Fig. 1. The extra SC cavity providing the very high voltage required by the SRFF scheme will be placed in one of the two Interaction Regions (IR2), while the KLOE experiment will remain installed in IR1. The optical functions of a possible solution for a high momentum compaction lattice ($\alpha_c = 0.08$) are shown in Fig. 2, while the expected bunch length along the ring with and without the extra voltage provided by the SC cavity is reported in Fig. 3.

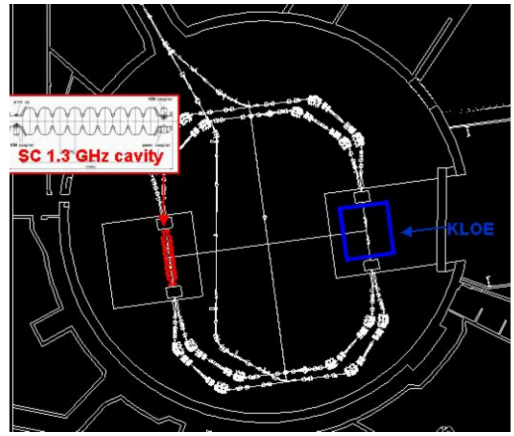

Figure 1: DAΦNE layout.

All DAΦNE quadrupoles are individually powered allowing a wide range of lattice flexibility. The high momentum compaction lattice is obtained with zero dispersion and dispersion derivative in both interaction points, and increasing the dispersion function only in the dipoles facing the two straight sections. A larger momentum compaction can be obtained by increasing the dispersion peaks in the zone near the wigglers and in the straight sections, but limitations in both physical and dynamical apertures begin to appear. Solutions for large and negative α_c values are also under study.

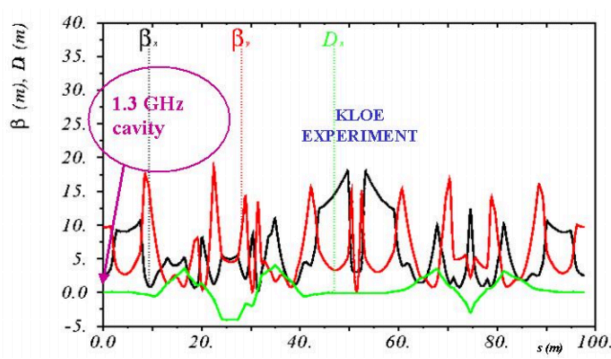

Figure 2: Lattice optical functions.

RF SYSTEM

According to (2), with $\mu = 2\pi/3$ and $\alpha_c = 0.08$, the ratio between the RF voltage and the RF wavelength (i.e. the RF slope) must be $V_{RF}/\lambda_{RF} \approx 30\ MV/m$.Due to the very high RF slope required, the use of SC technology is mandatory. According to (5), high frequencies will require low voltages but will provide less RF acceptance. The use of the 1.3 GHz SC RF technology developed for TESLA is a good compromise. An RF voltage of $7MV$ is necessary at that frequency, which can be safely provided by one 9-cells cavity powered at the moderate gradient of $7MV/m$. This choice is convenient and very compact.

The parameters of the SC RF system to be installed in DAΦNE for the SRFF experiments are listed in Table 2.

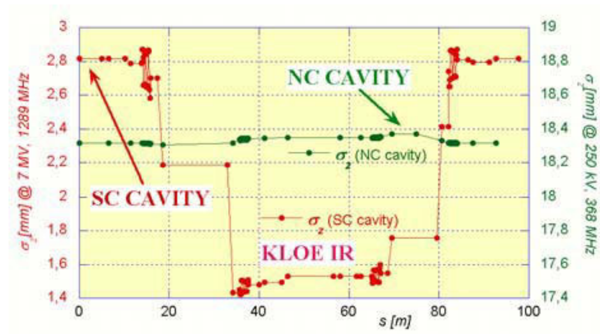

Figure 3: Bunch length along the ring.

Table 2: RF system for the SRFF experiment.

Cavity type		SC TESLA like, 9 cells
R/Q geometric factor	R/Q	500 Ω
Quality factor (@ 1.8 K)	Q_0	$1 \cdot 10^{10}$
Cavity wall power	P_{cav}	5 W
Loaded quality factor	Q_L	$2 \cdot 10^7$
Cavity detuning due to beam loading	Δf_{cav}	- 100 kHz (@ 7MV, I_b=1A)
RF generator power	P_{gen}	620 W
Cavity length	L_{cav}	1 m

The frequency of the SC cavity is about 0.85% lower than the standard TESLA one (1.289 GHz against 1.3 GHz) in order to be tuned on the 420th bunch revolution harmonic. Since the NC RF system of DAΦNE is tuned on the 120th revolution harmonics, the two systems can operate simultaneously to store up to 60 equidistant bunches. In this way the standard NC RF system will provide the power to compensate the beam losses, while the SC system will provide the large focusing voltage over the bunch. The input coupler needs also to be modified in order to increase the external Q value to $Q_{ext} \approx 2 \cdot 10^7$. An RF power source of 1 kW is sufficient to power the cavity in this case.

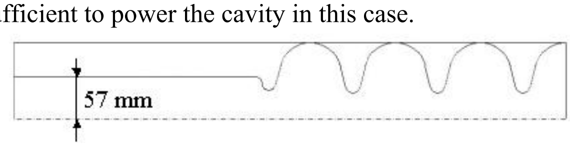

Figure 4: 7-cells structure with large beam tubes.

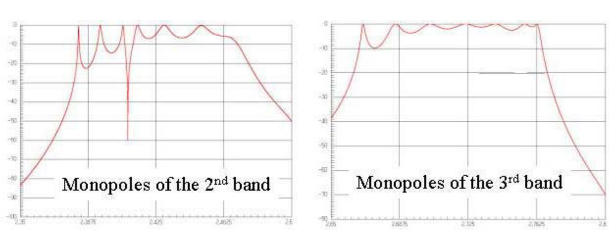

Figure 5: Damped propagating monopoles.

Other modifications of the TESLA multicell cavity design are under study to decrease the number of the HOMs trapped in the structure. Reducing the number of cells and enlarging the beam tubes seems to be an effective approach. A 2D model of a 7-cells cavity with enlarged beam tubes is shown in Fig. 4. Only the 1st monopole band remains trapped in this case. The other monopoles and the dipoles propagate in the beam tubes and can be damped by absorbing loads. The damped monopoles of the 2nd and 3rd band obtained with an HFSS simulation of the Fig. 4 model are reported in Fig. 5.

CRYOGENICS AND DIAGNOSTICS

The TESLA cavities have to be cooled with superfluid Helium at 1.8 K temperature. In the present configuration the DAΦNE cryogenic plant supplies standard liquid Helium to the SC solenoids of the KLOE and FINUDA detectors, and to 4 small-size compensating solenoids placed on both sides of the two experiments. In order to produce superfluid Helium the plant needs to be upgraded. The SC cavity and cryostat will occupy the place of the FINUDA magnet, which has been already rolled out from the beamline. The FINUDA transfer line, now transporting 5.2 K and 70 K cold Helium, will be used to supply an interface box. Here the 1.8 K superfluid Helium will be produced by means of a pumping system directly connected to the Helium bath.

At present, the upgrade of the cryogenic plant is under study, in particular concerning the pumping system. The machine diagnostics has also to be upgraded. We have a 1.5 ps resolution streak camera looking at the sinchrotron light emitted by the first dipole after the short straight section. At least another sinchrotron light line has to be derived from one of the dipole magnets close to the KLOE IR to measure the bunch length in the region where it is shortest.

CONCLUSIONS

The proposal of a Strong RF Focusing experiment at DAΦNE has been presented. A suitable high momentum compaction lattice (α_c = 0.08) has been designed and will be experimentally tested by the end of this year. The very high RF voltage required by the SRFF scheme will be provided by a TESLA-like SC cavity placed in the 2nd interaction region.

The RF design of the cavity is in progress. If the proposal will be funded, the mechanical design of the cavity and its cryostat will start immediately and we expect to complete the construction of these items in 2 years. Meanwhile, the DAΦNE cryogenic plant will be upgraded to provide 1.8 K liquid Helium to the cavity.

We have a two-months experimental activity plan for the end of 2006. The bunch length variation along the ring will be measured by means of a streak camera sampling the bunch length at least in two different positions. Storing high current (in the 0.5 A range) in multibunch mode in this regime is another important goal.

REFERENCES

[1] P. Raimondi, FRXBCH02, this conference
[2] G. E. Fisher, SPEAR Note 154, SLAC, Dec. 1972
[3] A. Gallo et al., e-Print Archive: physics/0404020
[4] C. Milardi, THOBCH02, this conference
[5] C. Biscari, MOPLT056, this conference