PROPOSAL OF A STRONG RF FOCUSING EXPERIMENT AT DAΦNE


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 $\beta_y$ to further squeeze the vertical beam size and decrease the effect of beam-beam interaction. This approach is effective only if the bunch length $\sigma_c$ does not exceed the $\beta_y$ 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 $\alpha_c$ 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:

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

where $L$ is the ring length, $\sigma_E/E$ 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 $\mu$ is the one-turn synchrotron phase advance given by:

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

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

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

For $\mu$ values close to $\pi$ 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 $\sigma_E/E$ in the SRFF regime is magnified by a factor $G$ with respect to the unperturbed value $(\sigma_E/E)_0$, with $G$ given by:

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

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 $\Phi$-factory DAΦNE is a double ring $\phi \phi^-$ collider working at the $\Phi$ 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 \( \beta_s \leq 1 \text{cm} \));
- 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 (\( I < 1 \text{mA} \)), high current in a single bunch (\( I = 10 \text{mA} \), to study the bunch lengthening process), high current in multibunch regime (\( I \approx 0.5 \text{A} \) in 60 bunches). The DAΦNE parameters for the SRFF experiment are reported in Table 1.

**Table 1: DAΦNE parameters for the SRFF experiment.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Momentum Compaction ( \alpha_c )</td>
<td>0.08</td>
</tr>
<tr>
<td>RF Frequency ( f_{RF} )</td>
<td>1288.973 MHz</td>
</tr>
<tr>
<td>RF Voltage ( V_{RF} )</td>
<td>7 MV</td>
</tr>
<tr>
<td>Harmonic Number ( h )</td>
<td>420 (= 3.5 \times 120)</td>
</tr>
<tr>
<td>Long. Phase Advance ( \mu )</td>
<td>( 2\pi / 3 )</td>
</tr>
<tr>
<td>Natural Energy Spread ( \sigma_E / E )</td>
<td>( 4 \times 10^{-4} )</td>
</tr>
<tr>
<td>Energy Spread ( @ \mu = 2\pi / 3 ) ( \sigma_E / E )</td>
<td>( 6 \times 10^{-4} )</td>
</tr>
<tr>
<td>Bunch Length ( \sigma_z )</td>
<td>1.3 - 2.5 mm</td>
</tr>
<tr>
<td>RF Acceptance (IP/RF) ( \Delta E / E )</td>
<td>( 7 \times 10^{-3} / 5 \times 10^{-3} )</td>
</tr>
</tbody>
</table>

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.

**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 \( V_{RF} / \lambda_{RF} \approx 30 \text{ MV/m} \). 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 7 MV is necessary at that frequency, which can be safely provided by one 9-cells cavity powered at the moderate gradient of 7 MV/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.
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 $Q_{ext} = 2 \cdot 10^9$. An RF power source of 1 kW is sufficient to power the cavity in this case.

**REFERENCES**

[1] P. Raimondi, FRXBCH02, this conference
[3] A. Gallo et al., e-Print Archive: physics/0404020
[4] C. Milardi, THOBCH02, this conference