BEAM - BEAM INTERACTION STUDY FOR DAΦNE

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Abstract

The right choice of a working point is very important for good collider performance.

We use a recently developed beam - beam simulation code in order to find a suitable working point for DAΦNE [1].

The performed tune scan shows reasonably large "safe" area around working points (ν_x, ν_y) = (0.09, 0.07) and (0.53, 0.06), which both have an optimum luminosity, acceptable tail growth and satisfactory dynamic aperture. The possibility to employ the two interaction points in DAΦNE is also analyzed.

1 INTRODUCTION

The working points situated close and above integer (half-integer) tune values seem to be preferable for satisfactory collider performance, of course, if this choice does not lead to degradation of a machine dynamic aperture. The main reasons for that are following:

- the smaller beam-beam tune spread, i. e. the smaller number of resonance lines crosses a beam footprint;
- the lower order resonance lines are less dense there;
- close (above) integers, dynamic beta [2] and dynamic emittance [3] effects play a significant role in the beam-beam interaction. The emittance grows slower than the beta function decreases as the tune gets closer to an integer. This leads to the beam size shrinking which can partly compensate the beam blow up.

Here, in order to find a suitable working point for DAΦNE we perform a scan in the tune areas close (above) to the integer (half-integer) tunes by using a recently developed beam-beam simulation code [4]. The simulation algorithm is fully symplectic in the 6-dimensional phase space, and includes all the known effects as the effects of the crossing angle, finite bunch length, variation of β along the bunch during collisions, energy loss due to the longitudinal electric fields etc.

Finally, we simulate the case of DAΦNE operating with two interaction points having the different horizontal betatron phase advance between them.

Table 1 summarizes the main DAΦNE parameters used in the beam-beam simulations.

Table 1. DAΦNE parameters relevant for simulations

Energy, E	510	MeV
Circumference, C	97.69	m
β_x at IP	4.5	m
β_y at IP	0.045	m
Emittance, ε_x	10^{-6}	m·rad
Emittance, ε_y	10^{-8}	m·rad
Bunch length, σ_z	0.03	m
Synchrotron tune, ν_z	0.012	
Particles/bunch, N	$9 \cdot 10^{10}$	
Crossing angle, ϕ	±12.5	mrad
Tune shifts, ξ_x/ξ_y	.04/.04	
Damping time:		
horizontal	110540	turns
vertical	109650	turns
longitudinal	54620	turns

2 COLLISIONS AT A SINGLE INTERACTION POINT (IP)

2.1 Working point (0.09; 0.07)

We find the dependence of beam sizes and the luminosity on the tunes by scanning ν_x - ν_y plane in the range of $0.01 < \nu_{x,y} < 0.21$. In order to examine the equilibrium beam sizes the beam-beam collisions and revolutions through the ring are simulated for up to 10 radiation damping times. Because of the rather long damping time in DAΦNE in terms of the revolution turns (about 10^5 turns) in order to save CPU time the scan is rather rough with a step of $\Delta\nu_{x,y} = 0.01$. The strong bunch is longitudinally sliced into 5 slices, and the weak one is represented by 50 superparticles. The luminosity is estimated by a convolution of the distribution function of the two beams.

Figure 1 shows a luminosity contour plot in the ν_x — ν_y plane. The darker areas correspond to the higher luminosities with the design luminosity being the maximum value. The contour spacing is 10% in luminosity reduction.

On the contour plot we can clearly see the reduction of luminosity due to various resonances: $\nu_x = \nu_y, \nu_x = 2\nu_y$, $6\nu_y = 1$ and others. The absolute minimum of the luminosity in the given tune region is near the intersection of the beam-beam resonances of the sixth order and the resonance $\nu_x = \nu_y$. The number of areas where the luminosity can reach the design value is limited: there are two areas near the vertical integer tune, one area is close to the horizontal integer tune and another one is situated between the resonances $\nu_x = \nu_y$ and $\nu_x = 2\nu_y$. Numerical simulations have shown that the three former areas have a very small dynamic aperture, while for the working points in the latter one a satisfactory dynamic aperture can be found [5].

In particular we consider a point $\nu_x = 0.09$; $\nu_y = 0.07$ as a possible candidate for the DAΦNE working point. For this working point the luminosity reaches 95% of the nominal value.

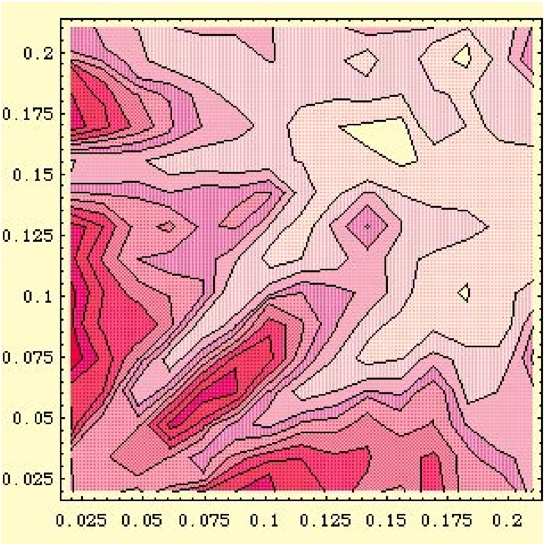

Figure 1 - Luminosity contour plot (scan). The abscissa and ordinate are the horizontal and vertical tunes, respectively.

For the chosen working point we repeat simulation with 500 particle in the weak beam and 10 slices in the strong one. The results do not differ substantially from those with 5 slices and 50 particles. After 10^6 turns the luminosity is equal to 95.3% of the design value.

The finer tune scan with a step of $\Delta\nu_{x,y} = 0.0025$ has been done in the vicinity of the working point which confirms that the tune area with an acceptable beam-beam performance is reasonably large.

2.2 Working point (0.53; 0.06)

Our main concern about the working point (0.09; 0.07) consists in the fact that it is situated rather close to the main diagonal ($\nu_x = \nu_y$) which could perturb the control of the coupling between transverse planes.

From this point of view a horizontal tune slightly above half integer would be preferable. The working point (0.52; 0.08) of the KEK B-factory is a good example [6].

We could expect also a better dynamic aperture for such a point. The working point (0.09; 0.07) lies near the strong resonance $\nu_x = 2\nu_y$ excited by sextupoles and appearing in the first order in perturbation, while the points above half integer are near the resonances appearing in the second order in the perturbation.

Hopefully, the DAΦNE lattice with the momentum compaction $\alpha_c = 0.02$ [5] is rather flexible giving the possibility to change the working point from (0.09; 0.07) to the working points above the half-integer in the horizontal plane by simple tuning of the magnet strengths without any mechanical adjustment.

We explore the tune region above the horizontal half-integer by performing the numerical tune scan in the range $0.51 < \nu_x < 0.6$; $0.01 < \nu_y < 0.1$.

Figure 2 shows the corresponding luminosity contour plot.

We can see a relatively large safe area near the vertical half-integer tune. In particular, the simulation for the working point (0.53; 0.06) with 500 particles in the weak beam and 10 slices in the strong one gives the luminosity which is equal to 98% of the design value, the maximum vertical amplitude of 24.6 σ_y and the maximum horizontal amplitude of 4 σ_x.

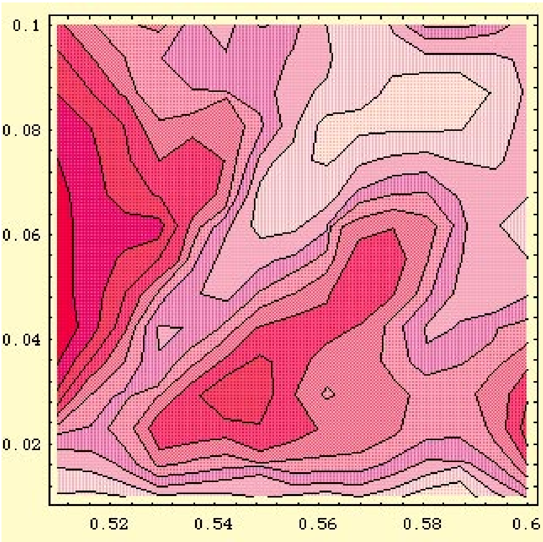

Figure 2 - Luminosity contour plot above horizontal half-integer. The abscissa and ordinate are the horizontal and vertical tunes, respectively.

3 ESTIMATES OF TAIL GROWTH

The growth of bunch tails due to beam-beam interactions for the two chosen working points, (0.09; 0.07) and (0.53; 0.06), has been studied with a long-term strong week calculation. The simulation have been done by tracking 50 superparticles over 10^8 turns.

Figures 3 and 4 show the calculated vertical particle distributions $\rho(I_y)$ as a function of the action variable I_y. Here we define the normalized vertical amplitude as $A_y^2 = 2I_y$.

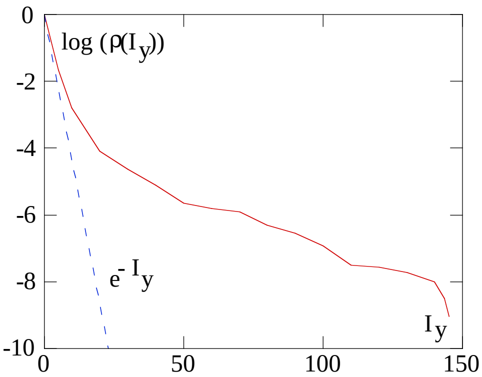

Figure 3 - Particle distribution in the vertical plane (working point (0.09; 0.07)).

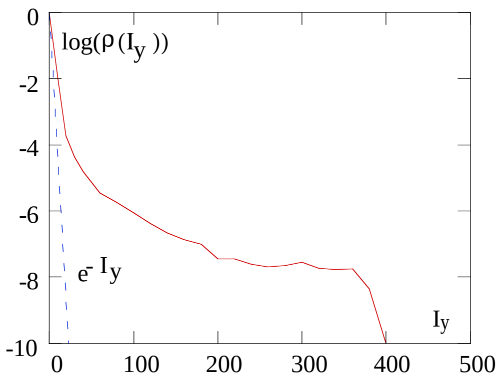

Figure 4 - Particle distribution in the vertical plane (working point (0.53; 0.06)).

The very core of the distributions has the nominal Gaussian distribution, while the non-gaussian tails are observed for the higher particle amplitudes. As it can be seen, only a very small fraction of the bunch population with $\log \rho(I_y) < 10^{-8}$ has vertical amplitudes beyond 17 σ_y for the working point (0.09;0.07) and 28 σ_y for the point (0.53; 0.06). The growth of horizontal bunch tails is much slower than in the vertical direction.

In order to get more precise information on the distribution at the higher amplitudes we are planning to use a recently developed code [7], allowing considerable reduction of the necessary CPU time, which showed a good agreement with the tracking for KEKB parameters [8]. However, since DAΦNE dynamical and physical apertures are larger than 70 σ_y at the coupling k = 0.01 [5], any substantial particle losses and background problems due to the beam-beam induced tails are not expected.

4 COLLISIONS AT THE TWO IP

The DAΦNE main rings consist of two rather different arcs ("Short" and "Long") having different horizontal phase advances between the two IPs.

It is known that phase advance differences between IPs break the symmetry of a collider, i. e. introduce new, low order resonances thus deteriorating the collider performance. In order to investigate a possibility to employ both IPs for the experimental study in DAΦNE we have simulated beam-beam collisions at these two IPs.

Table 2 and Table 3 show the tune advance between the two IPs in DAΦNE for two different working points.

Table 2. Tunes between IPs for the point (0.09;0.07)

	Short	Long	Total
ν_x	2.279	2.811	5.09
ν_y	3.035	3.035	6.07

Table 3. Tunes between IPs for the point (0.10;0.14)

	Short	Long	Total
ν_x	2.324	2.776	5.10
ν_y	3.070	3.070	6.14

Despite the differences in the horizontal tunes between IPs the weak-strong simulation for the nominal working point (0.09; 0.07) shows only a slight reduction in luminosity to 86% of the design luminosity value per each IP. For the other working point (0.14; 0.10), chosen for a comparison, luminosity drops from 61% with a single IP to 21% per each IP in the two IP collisions.

4 CONCLUSIONS

Simulations of the beam-beam interaction with an ideal linear lattice have shown that the two proposed working points both have an optimum luminosity close to the design value and acceptable tail growth.

However, the beam-beam study will continue in order to include the nonlinearities of the machine lattice and explore the bunch distribution tails at large amplitudes.

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