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SUPERB BUNCH-BY-BUNCH FEEDBACK R&D*

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Abstract

The SuperB project has the goal to build in Italy, in the Frascati or Tor Vergata area, an asymmetric e+/e- Super Flavor Factory to achieve a peak luminosity > 10**36 cm-2 s-1. The SuperB design is based on collisions with extremely low vertical emittance beams and high beam currents. A source of emittance growth comes from the bunch by bunch feedback systems producing high power correction signals to damp the beams. To limit any undesirable effect, a large R&D program is in progress, partially funded by the INFN Fifth National Scientific Committee through the SFEED (SuperB Feedback) project approved within the 2010 budget.

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INTRODUCTION

The SuperB project [1] has the goal to build in Italy, in the Frascati or Tor Vergata area, an asymmetric e+/e- Super Flavor Factory to achieve a peak luminosity > 10**36 cm-2 s-1. In the last and current years, the machine layout has been deeply modified, in particular the main rings are now shorter and an option with high currents has been foreseen. In the fig.1 the new SuperB layout is shown.

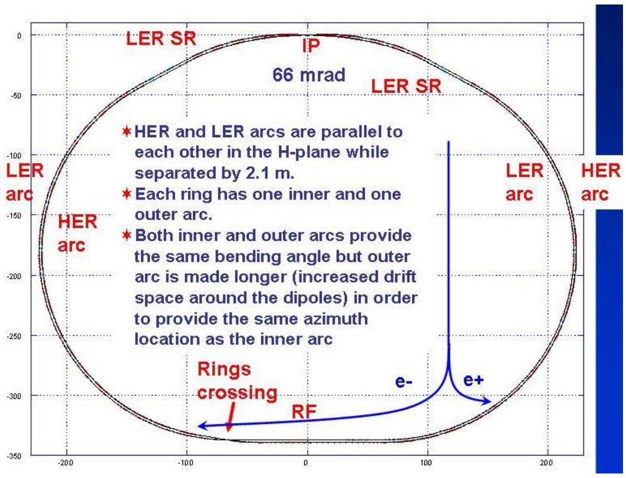
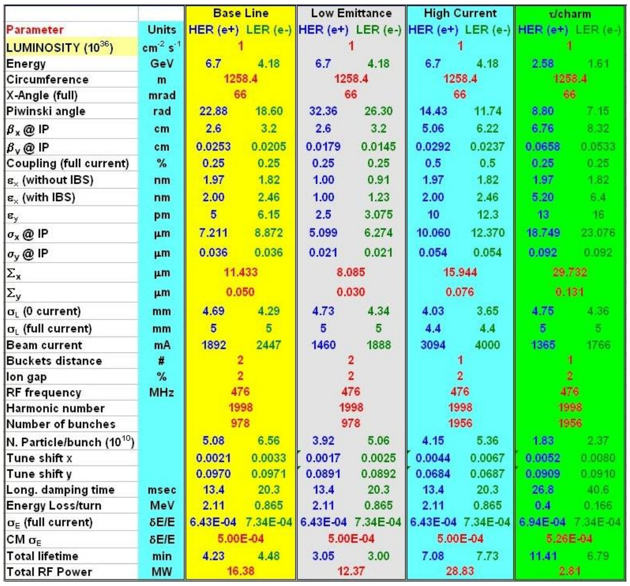


Fig. 1: SuperB layout

From bunch-by-bunch feedback point of view, the simultaneous presence in the machine parameters, of very low emittance, of the order of 5-10 pm in the vertical plane, and very high currents, at level of 4 Ampere for the Low Energy Ring, asks for designing very carefully the bunch-by-bunch feedback systems. The parameter list is presented in Fig. 2.

The bunch-by-bunch feedback design must take care of the risky and exciting challenges proposed in the SuperB specifications, but it should consider also some other important aspects: flexibility in terms of being able to cope to unexpected beam behaviours [2], [3] legacy of previous version experience [4], [5] and internal powerful diagnostics [6] as in the systems previously used in PEP-II and DAFNE [7].



		Base Line		Low Emittance		High Current		τ/charm	
Parameter	Units	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)
LUMINOSITY (10^{36})	cm^{-2} s^{-1}	1		1		1		1	
Energy	GeV	6.7	4.18	6.7	4.18	6.7	4.18	2.58	1.61
Circumference	m	1258.4		1258.4		1258.4		1258.4	
X-Angle (full)	mrad	66		66		66		66	
Piwinski angle	rad	22.88	18.60	32.36	26.30	14.43	11.74	8.80	7.15
β_x @ IP	cm	2.6	3.2	2.6	3.2	5.06	6.22	6.76	8.32
β_y @ IP	cm	0.0253	0.0205	0.0179	0.0145	0.0292	0.0237	0.0658	0.0533
Coupling (full current)	%	0.25	0.25	0.25	0.25	0.5	0.5	0.25	0.25
ε_x (without IBS)	nm	1.97	1.82	1.00	0.91	1.97	1.82	1.97	1.82
ε_x (with IBS)	nm	2.00	2.46	1.00	1.23	2.00	2.46	5.20	6.4
ε_y	pm	5	6.15	2.5	3.075	10	12.3	13	16
σ_x @ IP	µm	7.211	8.872	5.099	6.274	10.060	12.370	18.749	23.076
σ_y @ IP	µm	0.036	0.036	0.021	0.021	0.054	0.054	0.092	0.092
Σ_x	µm	11.433		8.085		15.944		29.732	
Σ_y	µm	0.050		0.030		0.076		0.131	
σ_L (0 current)	mm	4.69	4.29	4.73	4.34	4.03	3.65	4.75	4.36
σ_L (full current)	mm	5	5	5	5	4.4	4.4	5	5
Beam current	mA	1892	2447	1460	1888	3094	4000	1365	1766
Buckets distance	#	2		2		1		1	
Ion gap	%	2		2		2		2	
RF frequency	MHz	476		476		476		476	
Harmonic number		1998		1998		1998		1998	
Number of bunches		978		978		1956		1956	
N. Particle/bunch (10^{10})		5.08	6.56	3.92	5.06	4.15	5.36	1.83	2.37
Tune shift x		0.0021	0.0033	0.0017	0.0025	0.0044	0.0067	0.0052	0.0080
Tune shift y		0.0970	0.0971	0.0891	0.0892	0.0684	0.0687	0.0909	0.0910
Long. damping time	msec	13.4	20.3	13.4	20.3	13.4	20.3	26.8	40.6
Energy Loss/turn	MeV	2.11	0.865	2.11	0.865	2.11	0.865	0.4	0.166
σ_E (full current)	δE/E	6.43E-04	7.34E-04	6.43E-04	7.34E-04	6.43E-04	7.34E-04	6.94E-04	7.34E-04
CM σ_E	δE/E	5.00E-04		5.00E-04		5.00E-04		5.26E-04	
Total lifetime	min	4.23	4.48	3.05	3.00	7.08	7.73	11.41	6.79
Total RF Power	MW	16.38		12.37		28.83		2.81	

Fig. 2: SuperB parameter list

R&D AREAS

The R&D activities necessary for the SuperB bunch-by-bunch feedback start from a fundamental consideration: the very low beam emittance and transverse dimensions, in particular vertical, could have problems from the high power requested to the feedback systems to damp high current beam instabilities [8].

A second important consideration is based on the fast evolution of the electronics components [9] that asks for a refresh of the feedback parts due also to the SuperB schedule that foresees the first run after 2015. The electronics component evolution in terms of speed and integration makes also not more necessary and therefore potentially harmful to maintain two different designs for respectively the transverse and the longitudinal feedbacks.

In Fig. 3, a preliminary plot of the transverse and longitudinal system is sketched. In the scheme, the main features are summarized: a unified digital processing unit based on a single FPGA (Field Programmable Gate Array), 12-bit analog to digital conversion and 16-bit digital to analog conversion to have a better dynamic range in the digital modules. In fact the analog modules, included the power amplifiers, present a dynamic range of the order of 90 dB, and it follows that to keep the digital part with a dynamic range of about the half, involves the introduction of quantization noise making the digital part a sort of bottleneck, from this point of view.

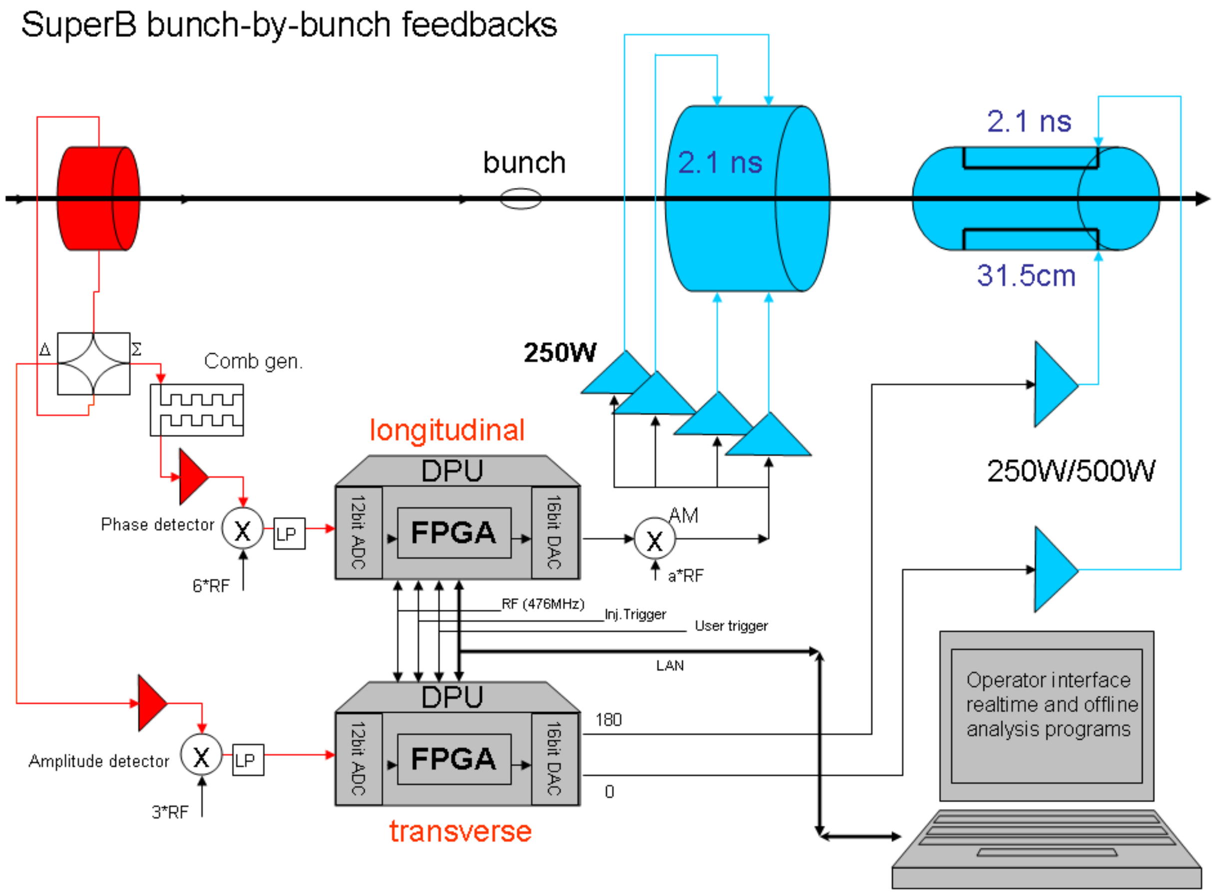


Fig. 3: Longitudinal and transverse bunch-by-bunch feedback systems (preliminary sketch)

Longitudinal dynamics model

With the goal to evaluate correctly the power needed as well as the best feedback transfer function, a longitudinal simulator has been under study.

The FORTRAN program Simul2 [10] has been developed at LNF for DAFNE in 1992-95 and consists in a complete tracking code that includes the RF High Order Mode, the beam behaviour (but not including collisions) and the bunch-by-bunch longitudinal feedback.

Beam-beam longitudinal consequences in crab-waist collisions with both large Piwinsky angles and crossing angles are important as it has been shown by experiments done during 2009 in DAFNE runs [11]. Nevertheless these effects, foreseen also in SuperB, should help to damp the other beam and not the contrary, so, at this level of simulation, they can be neglected.

The old FORTRAN program, after a fast porting from VAX/VMS environment to PC/Windows, has become the “core” of a simulator based on MATLAB. The old data entry was based on a simple editor, not very convenient for the SuperB parameters. Now the user interface can manage easily large harmonic numbers and big number of bunches (~2000). A limit of SIMUL2 is given by the output concerning time domain data about only 3 bunches, chosen by the operator. In fig. 4 the output data are presented in the high current case (4A) with bunches spaced by 1. An important result of this simulation is that the foreseen synchrotron instability can be damped by the longitudinal feedback system with a total power of 1kW, implemented by four 250W amplifiers feeding one cavity kicker with Rs>500Ohm. This power should be sufficient to control the beam longitudinal dynamics at 4A in LER.

Longitudinal growth rate evaluation

The simulator produces, as output, text files that can be analyzed by a simple spreadsheet or by MATLAB. A dedicated routine extrapolates the longitudinal growth rates in different cases.

The worst case, 4A beam current in 1956 bunches, generates very fast instability (mostly at new charge injection in the main rings).

Injecting bunch #2, the instability growth rates are of course faster in the nearby bunches than in the others along the bunch train. A summary is the following:

Bunch #11	==>	178 turns, 0.75 ms
Bunch #1225	==>	673 turns, 2.82 ms
Bunch #1955	==>	691 turns, 2.93 ms

Data from bunch #11 are shown in fig. 5: in blue the time domain tracking results, in red the exponential fit giving the growth rate estimation.

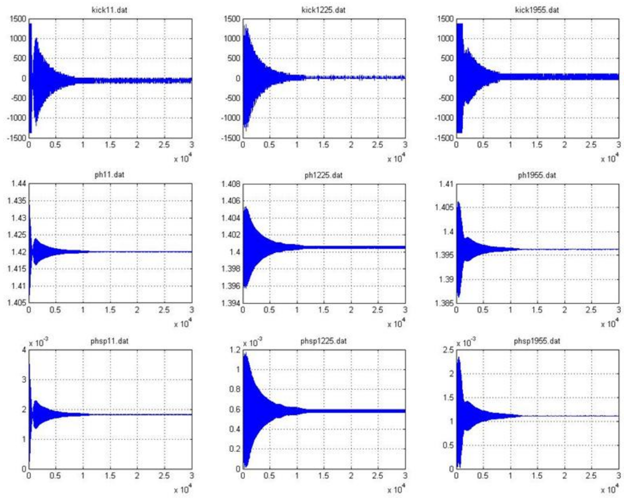


Fig. 4: Longitudinal model output with 4A beam current and bunch pattern spaced by 1. Plotted bunch: #11, #1225 and #1955; injected bunch: #2.

Transverse dynamics and feedback model

A simulator is necessary also for the transverse planes, but in this case a clear description of the instable mode source is missing. Therefore a much simpler approach, based on the graphic language SIMULINK, and inspired to other experiences [12] for computing feedback coefficients, is under study. In this case, there are only two elements in the loop: the beam, represented by the transfer function derived by the motion equation with the supposed worst instability growth rate and the feedback itself with its transfer function. An interesting feature of the SIMULINK environment is that it can generates directly the VHDL code to be downloaded to FPGA.

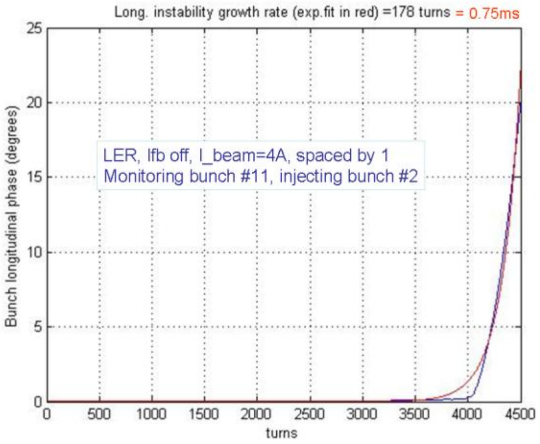


Fig. 5: Longitudinal growth rate evaluation

Hardware, gateware, and firmware

Partial implementations of the code in the XILINX Virtex-5/Virtex-6 FPGA are in progress. In particular an operator interface based on WEB-browser is under development to be used for fast data acquisition system and remote i/o management.

CONCLUSION

R&D activities for the SuperB bunch-by-bunch longitudinal and transverse feedback are well under way and everything seems to point out that the design will be accomplished within the SuperB schedule.

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