RF System Design for the PEP-II B Factory*

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Abstract

The paper presents an overview of the design of the RF system for the PEP-II B Factory. An RF station consists of either two or four single-cell cavities driven by a 1.2 MW klystron through a waveguide distribution network. A variety of feedback loops stabilize the RF and its interaction with the beam. System parameters and all the relevant parameters of klystron and cavities are given.

1. INTRODUCTION

The PEP-II B-factory project consists of two storage rings asymmetric in energy, the high energy ring (HER) filled with electrons at 9 GeV and the low energy ring (LER) filled with positrons at 3.1 GeV with a large number of bunches in each ring [1]. Following is a list of significant parameters for the machine relating to the design of the RF systems:

Table 1: PEP-II RF system parameters
(including the effect of a 5% gap in the beam)

PARAMETER	HER	LER
Energy (GeV)	9.0	3.1
Beam current (A)	1.03	2.25
Number of bunches	1658	1658
Bunch length (cm)	1.0	1.0
RF voltage (MV)	18.5	5.9
RF frequency (MHz)	476	476
Beam revolution frequency (kHz)	136	136

The challenges of the RF system design derive from the large number of bunches and the heavy beam loading, where the beam current in the LER cavity is a factor 6 larger than the generator current needed to produce the gap voltage. The large number of bunches require the reduction of the higher order mode (HOM) resonant Qs of the accelerating cavities and limit their allowable number in order to reduce the growth rate of multibunch instabilities. The heavy beamloading makes it necessary to operate the cavities detuned beyond the first lower beam harmonic, which makes the fundamental cavity impedance a large driving force for low mode multibunch instabilities. How these challenges affect the choice of system parameters and the system design is the subject of this paper.

2. CAVITY PARAMETERS

A single cell cavity was designed which incorporates heavy loading of a broad spectrum of higher order modes [2]. The single cell cavity design was chosen to minimize the number of higher order modes that can interact with the beam. The shunt impedance at the fundamental mode was optimized with re-entrant noses without significantly increasing the impedances of higher order modes. A fundamental mode shunt impedance of 3.5 MOhms (engineering notation) is expected, estimated by different simulation codes (URMEL, ARGUS, MAFIA) and de-rated for increased operating temperature and other spurious losses. Three HOM ports were added in strategic locations in the form of waveguides beyond cut-off for the fundamental accelerating mode with each terminating in a broadband (0.7 to 4.5 GHz) load capable of dissipating up to 10 kW [3]. The original machine RF layout called for a 925 kV gap voltage corresponding to 122 kW of wall dissipation, and a high power cavity capable of 150 kW wall dissipation was designed [4]. A re-optimization of the machine allowed the gap voltage to be reduced to 770 kV corresponding to a maximum of 85 kW wall loss but the cavity design for 150 kW was retained allowing for additional safety margin.

The coupling factor was set to 3.6, the same for both rings, in order to get the same time response of each cavity field to the perturbation caused by the 5% ion clearing gap. This gap is introduced in the HER to clear trapped ions, a similar gap is used in the LER to force the bunches in each ring to respond the same and collide in the center of the interaction region.

The vacuum window of the cavity has to be able to transmit power to make up the wall losses in the cavity as well as power lost by the beam. A window capable of handling 500 kW of CW power is being designed at SLAC [5] with first power tests due in Fall 1994. The window is being placed 1/2 wavelength away from the detuned short position of the cavity in order to tie its electric field level to the field of the cavity itself. This placement will avoid excessive electric field levels across the ceramic of the window as a result of large reflections after a sudden beam loss and will thus help to protect the window from damage due to arcing (see Fig. 1).

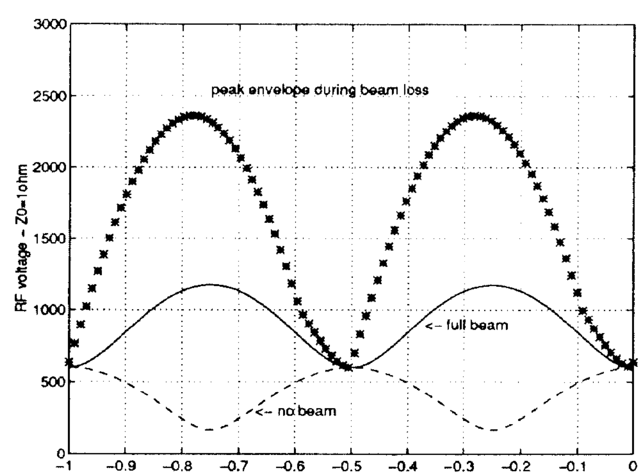

Figure 1. Voltage standing wave pattern in the drive line to a cavity in the low energy ring

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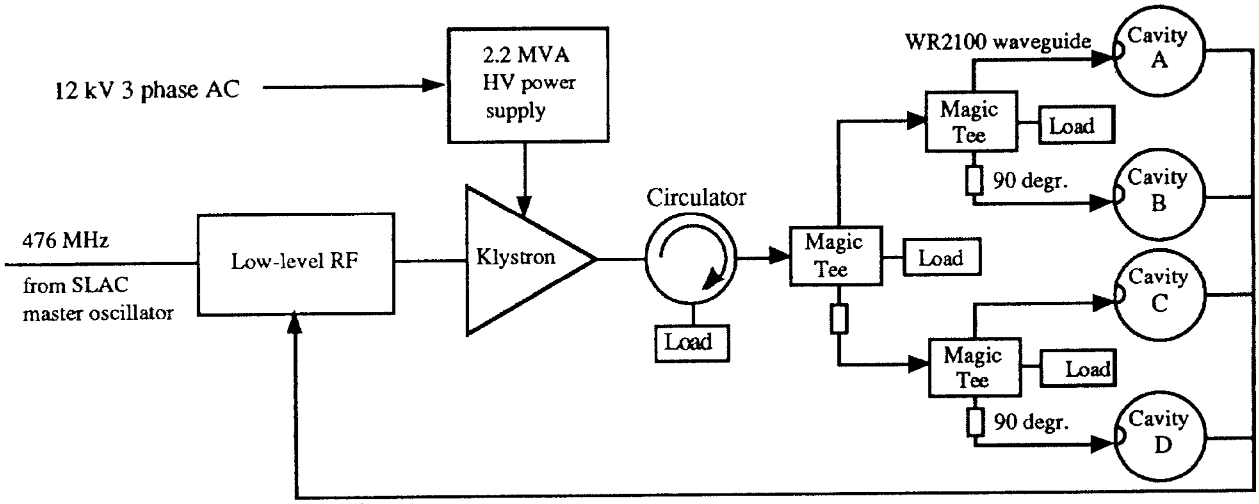

Figure 2. HER RF station block diagram

Table 2: Cavity design parameters

PARAMETER	
RF frequency (MHz)	476
Shunt Impedance R_s (MΩ) [a]	3.5
Max. gap voltage (MV)	1.02
Accelerating gradient (MV/m)	4.6
Wall loss/cavity (kW)	150
Coupling factor without beam (β)	3.6
Unloaded Q of cavity[b]	~30000

[a] $R_s = V^2/2P$

[b] with ports, at 40°C

3. SYSTEM LAYOUT

An overall system layout was established using the above cavity parameters and a 1.2 MW power source similar to those available in industry. The high energy ring is operated with 6 klystron stations and 24 cavities, each four cavities driven by one klystron (see Fig. 2). Similarly the low energy ring has 5 klystron stations driving 10 cavities, two cavities per klystron. With this system layout both rings can operate with full beam current and slightly increased bunch-length (1.15 cm instead of 1 cm) with one station idle in each ring. This requirement is driven by PEP-II being designated a "factory" with an up-time of more than 75% and the possibility of a station being in a maintenance mode despite a rugged design philosophy.

Table 3: Station parameters

PARAMETER	HER	LER
Number of klystrons	6	5
Number of cavities	24	10
Gap Voltage (MV)	0.77	0.59
Accelerating gradient (MV/m)	3.4	2.6
Wall loss/cavity (kW)	85	50
Coupling factor without beam (β)	3.6	3.6
Klystron power with beam (MW)	1.03	.82
Reflected power w. beam/sta. (kW)	12	83
Beam power/cavity (kW)	160	302
Total power/window (kW)	245	393
Cavity detuning with beam (kHz)	-73	-206

A circulator is used to protect the klystron output window and allow for stable klystron operation. It also provides a matched source for the cavities, which improves beam stability. The power is divided by Magic-Tees and the cavities are placed an odd number of quarter wavelengths apart. This combines emitted power from the cavities into a 1.2 MW load at the fourth port of the Magic-Tee. The arrangement shields the circulator from the large emitted power spikes from each cavity, which can reach as much as four times the maximum drive power of 500 kW per cavity when the beam is suddenly lost.

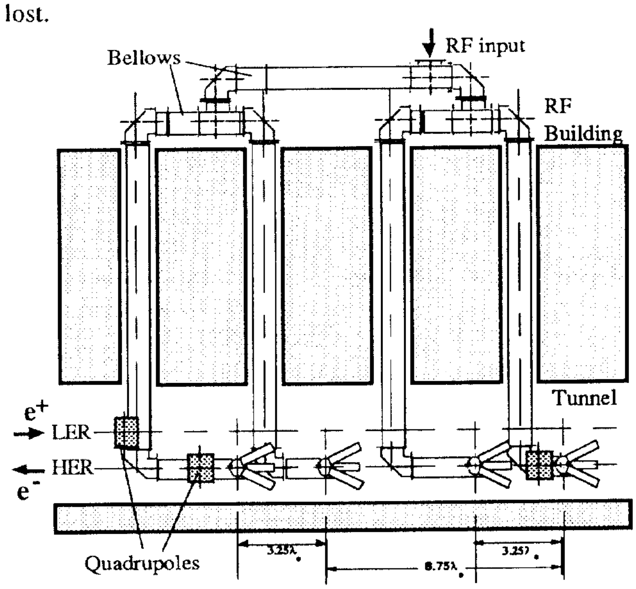

Figure 3. Cross-section of waveguide layout with 4 cavities in tunnel

The design of the waveguide network is guided by the following requirements:

1) Minimize electrical length.
2) Dissipate potentially large reflected power in the Magic-Tee loads to protect the circulator.
3) Phasing of RF fields in the cavities correctly for acceleration of the respective beams.
4) Match the signal delay to each cavity to beam arrival time in each cavity within ±0.5 wavelengths for fast feedback.

The electrical length is minimized by choosing the largest applicable waveguide size, WR2100, which has the highest group velocity of 0.8c and thus will exhibit the lowest delay. A layout of the cavities in the tunnel has been chosen in which a pair of cavities is separated on the beam line by 3.25 wavelengths and each pair in a set of 4 cavities is separated by 8.75 wavelengths. Using these separations all cavities fit in between the quadrupoles, and the divider network is simple. The acceleration phase of each cavity can be adjusted by changing the length of bellows in the divider arms. The signal delay differences are 0.2 wavelengths for the 3.25 wavelength separation and 0.08 wavelengths for the 8.75 wavelength separation, which are well within the specification for the RF feedback circuits.

3. RF FEEDBACK CIRCUITS

In order to reduce the impedance of the detuned fundamental resonance of the cavities as seen by the beam bunches, the 3.5 MOhms shunt impedance of the cavity has to be reduced to about 4.2 kOhms per cavity, a level where remaining multibunch oscillations can be damped by the longitudinal feedback system. Figure 4 shows how the impedance reduction is accomplished by several feedback loops [6][7[[8][9]. An initial reduction by a factor of 4.6 comes from the fact that the cavities are over-coupled with a beta of 3.6 and the source is matched by Magic-Tee loads and the circulator. A direct RF feedback loop around cavity and klystron is used to gain a factor 10, limited by delay around the loop. For this reason a low delay in the klystron is desirable. Further reduction in impedance of up to a factor of 100 is achieved by the use of a digital comb filter feedback with a one turn delay, which places demands on the klystron bandwidth. Additional feedback gain can be added by filtering the lowest multibunch modes out of the longitudinal feedback system and using the RF system as a powerful kicker.

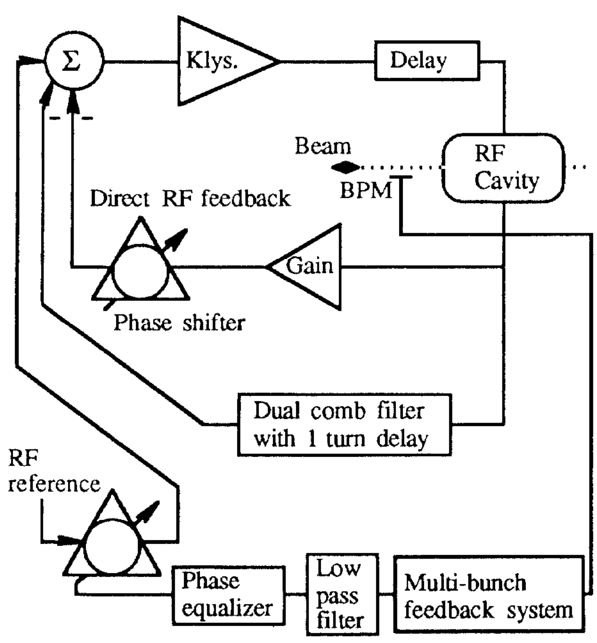

Figure 4. Block diagram of RF feedback circuits

4. KLYSTRON PARAMETERS

To meet the above requirements a 476 MHz klystron of about 1.2 MW CW saturated power level is required. It will operate 10% below saturation to allow for amplitude modulation as required by the feedback circuits. The klystron is specified to exhibit a -1dB bandwidth of >3 MHz and a delay of <150 nsec. The klystron is required to operate very stable, without any spurious sidebands and after meeting the above requirements should also perform with good efficiency. A klystron with the described parameters was designed by the SLAC Klystron Department in cooperation with VARIAN ASSOC. Its efficiency is expected to be 60% at saturation. The prototype will be tested in the Fall of 1994.

Table 4: Klystron parameters

PARAMETER	
Frequency (MHz)	476
Saturated output power (MW)	1.2
1 dB bandwidth (MHz)	>3
Group delay (nsec)	<150
Beam voltage [kV]	83.5
Beam current [A]	24.1
Efficiency at saturation (%)	60

5. CONCLUSION

An optimized RF system has been designed and simulated in detail that is expected to perform well under the heavy beam loading condition of the PEP-II B Factory. Special care has been taken to design a robust system allowing a large up-time of the machine.

6. ACKNOWLEDGMENTS

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