Title
An RF Cavity for the B-Factory

Authors
Rimmer, R.A.
Voelker, F.
Lambertson, G.
et al.

Publication Date
1991-04-01

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

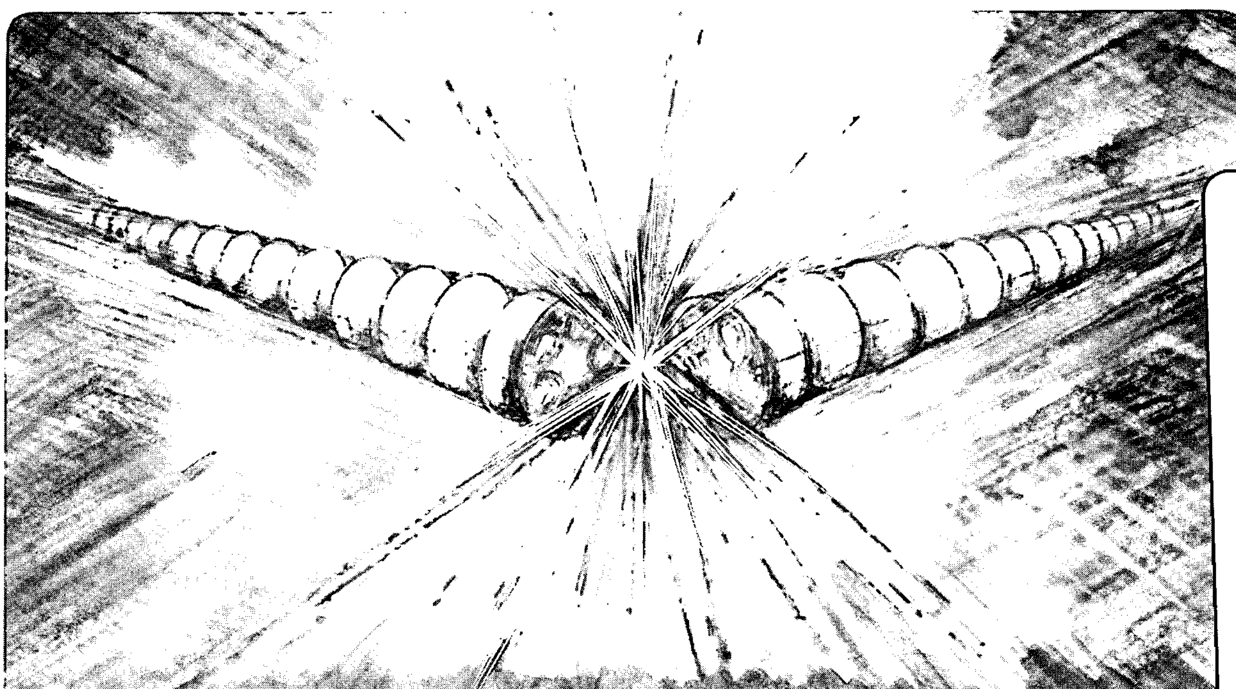
Accelerator & Fusion Research Division

Presented at the IEEE Particle Accelerator Conference, San Francisco, CA, May 6–9, 1991, and to be published in the Proceedings

An RF Cavity for the B-Factory

R. Rimmer, F. Voelker, G. Lambertson, M. Allen, J. Hodgeson, K. Ko, R. Pendleton, H. Schwarz, and N. Kroll

April 1991



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

BECON-91
LBL-30624

An RF Cavity for the B-Factory

R. Rimmer, F. Voelker, G. Lambertson,
Lawrence Berkeley Laboratory,
University of California
Berkeley, CA 94720

and

M. Allen, J. Hodgeson, K. Ko, R. Pendleton, H. Schwarz,
Stanford Linear Accelerator Center
Stanford, CA

and

N. Kroll, University of California
San Diego, CA

April 1991

* Work supported by the Director, Office of Energy Research, Office of High Energy Physics, Advanced Energy Projects Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

An RF Cavity for the B-Factory*

R. Rimmer, F. Voelker, G. Lambertson, LBL,#
M. Allen, J. Hodgeson, K. Ko, R. Pendleton, H. Schwarz, SLAC‡,
N. Kroll, UCSD†/SLAC

Abstract

The paper describes the proposed design for the 476 MHz accelerating cavity for the SLAC/LBL/LLNL B-Factory. This machine will require a high power throughput to the beam because of the large synchrotron radiation losses, and very low impedances for the higher order modes because of the high current proposed. Use of conventional construction in copper means that careful consideration has to be paid to the problem of cooling. The need for a high shunt impedance for the accelerating mode dictated the use of a re-entrant shape. This maximized the impedance of the fundamental mode with respect to the troublesome longitudinal and deflecting higher order modes, when compared to open or "bell shaped" designs. A specialized damping scheme was employed to reduce the higher order mode impedances while sacrificing as little of the fundamental mode power as possible. This was required to suppress the growth of coupled bunch beam instabilities and minimize the workload of the feedback system needed to control them. A window design capable of handling the high power was also required.

I. INTRODUCTION

The B-Factory RF system is required to meet the demands of a high luminosity, and therefore high current, while operating in a reliable manner befitting the "factory" philosophy of the project [1]. Choices of the parameters of the RF cavity are intended to be conservative and reasonable extrapolations from existing technology. The chosen frequency of 476MHz is a subharmonic of the SLAC linac frequency, to allow for stable injection. Commercial 1MW Klystron designs can be made to work at this frequency The very large beam currents, 1.48A in the High Energy Ring (HER) and 2.14A in the Low Energy Ring (LER), require up to 10MW and 5MW respectively to replace the energy lost to synchrotron radiation, cavity wall heating, and other effects. The need for short bunches (σ_l =1cm), requires a voltage of 18.5MV for the HER, 9.5MV for the LER. Unfortunately the number of cavities over which the power can be distributed must be kept to a minimum because, with such large currents, the impedances of higher order modes (HOMs) will cause very large longitudinal and transverse coupled-bunch instablility growth rates. Even so it is necessary to provide damping of these modes in the cavities and an active bunch-by-bunch feedback system in each ring to control this. Since most of the power goes into the beam, the saving in RF power from using superconducting cavities would not be large, and has to be weighed against the increased complexity associated with the cryogenic system. Also the technology for coupling such large drive and HOM power to and from a superconducting cavity is not yet mature. For these reasons and because expertise in the project team is primarily with room temperature structures, conventional copper construction was preferred. Single cell cavities of a re-entrant design were chosen to maximize the shunt impedance of the fundamental mode with respect to HOMs. It was decided to limit power to 500kW in each cavity (and window), of which up to 150kW is dissipated in the walls, yielding 20 cavities in the HER and 10 in the LER. This gives a gap voltage in the cavities of less than 1MV and an average field of about 4.3MV/m. The high wall dissipation requires careful attention to be paid to the cooling system, especially around structures such as the damping waveguides, which may have localized concentrations of current

*Work supported by the Office of Energy Research, Office of Basic Energy Sciences, U.S. Department of Energy.
Lawrence Berkeley Lab.,DOE contract DE-AC03-76SF00098
‡ Stanford Linear Accelerator Center, DE-AC03-76SF00515
† U.C.San Diego, DOE contract DE-AC03-89ER80726

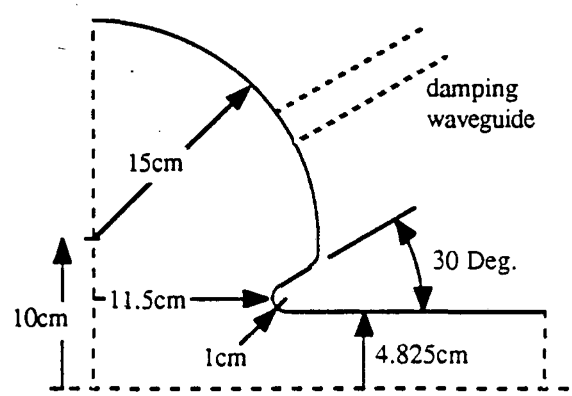


Fig.1: Basic B-Factory cavity shape

II. CHOICES FOR CAVITY PARAMETERS

Cavity designs and commercial 1MW CW klystrons are available at around 350MHz and 500MHz. PEP, LEP and APS use 350MHz, while Daresbury (SRS), KEK and ALS operate at 500MHz. A frequency in the higher region was chosen because less overvoltage is required in the cavity to achieve the short bunch length and more bunches can be circulated.

The type and shape of the cavities is determined by the need to maximize the fundamental mode shunt impedance with respect to HOMs. This is best achieved with a re-entrant or "nose-cone" shape. With conventional copper construction, an open or bell shape, as often used in superconducting cavities, does not work as well in this respect. The shape chosen (fig.1) is similar to those used in the SRS, KEK and ALS, with a beam pipe internal radius of 4.825cm, (coming from the internal dimensions of a standard sized 10cm OD pipe used for the vacuum chamber in the RF straight). Analysis of the basic shape was done using the 2D URMEL code [2] Single cells were chosen to keep the number of HOMs to a minimum, in multi-cell structures the coupling between cells results in more modes.

URMEL calculates the transit time corrected shunt impedance R_s ($=V^2/2P$) for the basic shape to be about 5.3MΩ with a Q of 45,000 and R/Q of 116Ω. In a real cavity this impedance is degraded by the addition of ports and damping waveguides and by the effect of wall temperature on the conductivity of the copper. Experience with other designs suggests about 10% will be lost with the addition of the tuner, drive and other ports. Using MAFIA [3] and ARGUS [4] to study the 3D shape shows a loss of 10% or less in the fundamental mode R_s and Q when the damping waveguides are added (R/Q stays about the same). Based on extrapolation from existing cavities and thermal studies using ANSYS [5], loss of efficiency due to surface temperature rise may be as high as 14% with 150kW dissipated in the cavity. Thus a practical shunt impedance of 3.5MΩ with a Q of about 30,000 should be achievable, (table 1).

To get the required match at the nominal operating currents requires a coupling factor β of about 3.7. Loop and aperture couplers were considered, the loop has the advantage that the coupling factor can be adjusted by rotating it, but it must be well cooled because of the very high surface current densities. An aperture has the advantages of simplicity and lower surface currents but may need a larger opening in the cavity and requires a sliding short circuit in the waveguide to adjust the match which may be a problem because of limited space in the tunnel. A loop is favored because of the compactness and adjustability and because of the experience of the SLAC team with this type of coupler.

Either type of coupler requires the use of a vacuum window at some point. Existing designs using a ceramic window in the aperture or as part of the loop structure are not well suited to such high power levels. It was decided to locate the window well away from the harmful cavity standing wave fields, which may evanesce some distance into the waveguide, using a simple waveguide window. Designs are being developed commercially for 500kW CW operation. The location of the window in these designs requires that part of the waveguide be evacuated which may increase conditioning time. Anti-multipactor coatings will be applied to the windows and may be used on other surfaces if any problems are encountered with excessive multipactor during conditioning.

Active tuning of the cavities is proposed to be done by motorized plungers of the type used in PEP. These have carbon brushes to prevent HOM power from getting into the bellows. An interesting alternative is to distort the cavity slightly by external pressure to change its frequency. This has the advantage that no hole needs to be cut in the cavity wall. Both of these methods will be investigated in more detail.

Table 1: RF Parameters for the high and low energy rings.

Parameter	HER	LER
RF frequency (MHz)	476	
Beam current (A)	1.48	2.14
Number of cavities	20	10
Shunt Impedance R_s* (MΩ)	3.5	
Gap Voltage (MV)	0.93	0.94
Accelerating gradient (MV/m)	4.2	4.3
Wall loss/cavity (kW)	122	130
Coupling factor without beam (β)	3.7	3.8
Unloaded Q of cavity	30000	

* $R_s = V^2/2P$

The high beam currents have the potential for very high coupled-bunch instability growth rates, requiring special attention to be paid to the HOM impedances of the cavities. Existing damping techniques using externally applied tuned couplers have not proved effective enough to meet the B-Factory requirements, and reduce the growth rates to a level where an economically feasible feedback system could take control. For this application damping waveguides were included in the design of the cavity right from the start. These waveguides are designed to propagate at the HOM frequencies and are positioned to couple most strongly to the most troublesome modes while avoiding the field nulls of all the other modes (so that no modes, however innocuous, remain trapped). The waveguides are below cutoff at the fundamental mode frequency and result in only a small perturbation of the accelerating field. The effect of the size, shape and location of the damping waveguides has been studied experimentally on a simple pillbox cavity [6] and calculated using MAFIA and ARGUS, for the pillbox case and realistic B-Factory cavity shapes. Neither MAFIA nor ARGUS is currently capable of solving the complex eigenvalue problem created by lossy materials in the damping waveguides so the method of Kroll and Yu [7,8] was used to calculate the mode frequencies and Q's of the loaded structures. Three waveguides are used, spaced 120 degrees apart around the cavity azimuth so that all HOMs up to sextupole (m=3), and many higer orders, can be damped. This maintains symmetry, avoiding introducing low order (m=1,2) multipole components into the fundamental mode .

Experiments on the pillbox cavity showed that strong damping of HOMs can be achieved, and the measured Q's agreed well with those calculated by MAFIA/Kroll-Yu. Initially it was intended to get the Q's down to below 100 for the worst modes, on the pillbox this was achieved with only a 8% (calculated) loss in fundamental mode. Loaded Q for the longitudinal (m=0) TM011 mode was calculated to be between 15 and 35, measured to be 31. The dipole (m=1) TM110 mode was calculated to have a Q of 55, measured to be 37.

The first attempt to calculate the damping of the B-Factory cavity used a model having three rectangular waveguides with a cut-off frequency of about 600MHz. These waveguides were too broad to join directly to the cavity wall so an iris was used. Results for this geometry show strong damping of the worst HOMs, with a Q of about 30 for the TM011 mode, with about 12% loss of the fundamental mode Q (table 2). It may be possible to reduce this degradation of the fundamental mode by smoothing out the sharp corners in the iris. In an attempt to dispense with the iris altogether a scheme was developed using smooth ridged waveguides which can be made small enough to open directly into the cavity. Using this scheme the Q of the TM011 mode is reduced to less than 26 (possibly as low as 12 - there is some uncertainty due to the limited number of data points used in the Kroll-Yu method), while the fundamental mode Q is lowered by only 7%. The ridged waveguides have a slightly larger area, which may account for the stronger damping, while the smoothing of the corners and the lack of iris could explain the reduced perturbation of the fundamental mode. Other HOMs are reduced to Q's in the range 30-50, except for the TM020 which was accidentally missed by the placement of the ridged waveguide. (When the waveguide shape was changed the effective center of the waveguide moved slightly, onto a null of the TM020 magnetic field).

Table 2: Damping of prototype cavity by waveguides.

mode	No Waveguides freq (MHz)	Q_0	RT^2 (MΩ)	Rect wg+iris Freq (MHz)	Q_L	Ridged wg Freq (MHz)	Q_L
TM010	480	40003	4.71	475	35248	473	37344
TM011	750	33270	1.35	745	30	738	12- 26
TM020	993	38700	0.009	997	>1000	992	>5600
			Trans.* (MΩ/m)				
TE 111	685	54844	0.191	680	~65	678	30- 47
TM110	794	57762	18.3	795	~73	793	31- 64
TM111	1068	51836	33.2	1040	>50	1038	>49

* $R/k(r)^2$ (where r is the beam pipe radius=0.04825m)

Work is continuing on the optimization of the shape and position of the damping waveguides to get the lowest Q's for the most significant modes and to check all the higher order modes to make sure none are missed. Additional damping may be achieved by using higher order mode filters in the drive waveguide as there will be significant transmission through the power coupler for many HOMs. As a last resort any single mode which still has a significant impedance may be tackled by a tuned antenna inserted through a service port.

The high power dissipation and multiple apertures in the B-Factory cavity require careful attention to the problem of cooling. It is proposed to use a construction similar to that of the Daresbury and ALS cavities where the cooling water is channeled between two shells forming the inner and outer surfaces of the cavity. Particular care must be taken to ensure adequate cooling of the nose-cones and the damping waveguide apertures. The surface power dissipation is available from the numerical codes and this information can be transferred to a finite element program to perform thermal and, ultimately, stress analyses of the proposed designs. Early investigation suggested there might be strong local heating in the nose-cone region and around the rectangular waveguide iris. Current work is taking account of these results and the present design iteration is including a wider nose-cone angle (30 degrees) which allows easier access for the cooling water, and will feature a smoothed iris or rounded ridged waveguide.

Field enhancement on the small radius of the cavity nose-cone, as calculated by URMEL, leads to local surface electric fields about 5.9 times the average accelerating field in the cavity. At about 25MV/m this is comparable to the Kilpatrick number at this frequency, 20.9MV/m, so sparking should not be a problem after conditioning.

III. DEVELOPMENT PROGRAM

The current design effort is targeted on optimization of the RF performance of the cavity shape and the damping scheme, while keeping in mind the problems of cooling and mechanical construction. The first test of the design will be the construction of a low power test model to measure the effectiveness of the damping scheme and confirm the calculated mode spectrum. An automatic bead-puller is being constructed to allow detailed investigation of the HOM impedances. This model may also be used to test the RF control loops, using a low power amplifier instead of the klystron. At the same time programs will be under way to evaluate high power window and coupler designs, leading ultimately to their verification in a high power test stand at SLAC. Any lessons learned from the low power tests will be included in the next design iteration of the cavity which will concentrate on the engineering of a high power prototype.

IV. REFERENCES

[1] "An Asymmetric B-Factory based on PEP," Conceptual Design Report, LBL PUB-5303, SLAC 372

[2] U. Laustroer, U. van Rienen, T. Weiland, "URMEL and URMEL-T Userguide," DESY M-87-03, Feb 1987.

[3] "Reports at the 1986 Stanford Linac Conference., Stanford, USA, June 2-6 1986," DESY M-86-07, June 86

[4] A.Mondelli, et.al. "Application of the ARGUS Code to Accelerator Design Calculations," Proc. 1989 PAC, Chicago IL, March 20th-23rd, 1989.

[5] From Swanson Analysis Systems Inc., Johnson Road, P.O.Box 65, Houston, PA, 15342-0065.

[6] F. Voelker, G. Lambertson, R. Rimmer, "Higher Order Mode Damping in a Pill Box Cavity," Proc. 1991 PAC, San Francisco, May 6-9th. 1991. LBL-30625, BECON-92

[7] N. Kroll, D. Yu, "Computer Determination of the External Q and Resonant Frequency of Waveguide Loaded Cavities," SLAC-PUB-5171.

[8] N. Kroll, R. Rimmer, "Computer Determination of HOM Damping for a prototype JLC Accelerator Cavity and a prototype B-Factory Cavity," Proc. 1991 PAC, San Francisco, May 6th-9th. 1991.

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
INFORMATION RESOURCES DEPARTMENT
BERKELEY, CALIFORNIA 94720