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University of Wisconsin-Synchrotron Radiation Center **TECHNICAL NOTE**	**File No.** **SRC-206**	**Page** 1 of 17
Subject: **Instability modeling for passive harmonic-cavity operation at MAXlab**	**Author(s):** **R. A. Bosch**	
	Date: **March 26, 2004**	

ABSTRACT

Instability modeling is performed for passive harmonic-cavity operation at MAXlab. For the MAX-II 1.5 GeV ring, we consider the 100-MHz/500-MHz RF system now being constructed with three fundamental cavities and one harmonic cavity. We also model the existing 500-MHz/1500-MHz system on MAX-II. For the MAX-III 700 MeV ring, we model a 100-MHz/500-MHz RF system with one harmonic cavity, and a system with two identical harmonic cavities. For the proposed MAX-IV 1.5-GeV ring, we model a 100-MHz/500-MHz RF system with four fundamental cavities and one harmonic cavity. For the proposed MAX-IV 3-GeV ring, we model a 100-MHz/500-MHz RF system with ten fundamental cavities and two harmonic cavities.

Instability plots are shown which predict the current range where optimal bunchlengthening by the harmonic cavity is stable. We note the calculated coupled-dipole Robinson frequency, at which a large amount of phase noise on the beam may be expected. In addition, the bunchlengths are calculated for the case without a harmonic cavity and for optimal bunchlengthening.

1. Introduction

The MAX-II 1.5-GeV electron storage ring presently utilizes a 500 MHz fundamental RF frequency with four third-harmonic bunchlengthening cavities [1]. To provide sufficient RF power to operate two superconducting wigglers at the full beam current of 300 mA, an RF system is being constructed with three 100-MHz fundamental RF cavities and a fifth harmonic bunchlengthening cavity. Using analytic modeling and simulations described in References [2] and [3], instability modeling is performed for the MAX-II RF system being constructed and for the existing MAX-II RF system. For the MAX-III 700-MeV storage ring under construction, we model a 100-MHz/500-MHz RF system with one or two fifth-harmonic cavities. We also model 100-MHz/500-MHz RF systems for the proposed MAX-IV rings.

We use the notation of Ref. [2], in which the impedance of an RF cavity is one-half of the linac definition used in Ref. [1]. To model coupled bunch instabilities from parasitic RF modes, we use parameters ω_{CB} and $Z(\omega_{CB})$ for the angular frequency and impedance of a typical higher-order cavity mode at Aladdin [4]: $\omega_{CB}/2\pi = 1$ GHz and $Z(\omega_{CB}) = 10$ kΩ.

In the MAXlab modeling, we utilize two features recently added to the computer codes [5]. A nonzero load angle of the fundamental RF cavity θ_{v1} may be described by using the following equation for the tuning angle of the fundamental cavity [6]

$$\phi_1 = \tan^{-1}\left[2F_1 I R_1 \sin\psi_1 / V_{T1} - \tan\theta_{v1}\left(1 + 2F_1 I R_1 \cos\psi_1 / V_{T1}\right)\right] \tag{1}$$

For operation in the compensated condition ($\theta_{v1} = 0$), eq. (1) reduces to eq. (21) of Ref. [2]. In simulations, the initial conditions for the RF in-phase and quadrature voltage contributions from wake fields were changed from zero to the equilibrium values of

$$V_{bc1} = -2F_1 I R_1 \cos^2\phi_1, \quad V_{bs1} = F_1 I R_1 \sin 2\phi_1, \quad V_{bc2} = -2F_2 I R_2 \cos^2\phi_2, \quad V_{bs2} = F_2 I R_2 \sin 2\phi_2 . \tag{2}$$

For a given set of ring parameters, instability predictions for a variety of harmonic-cavity tuning angles and ring currents are first obtained from analytic formulas. A symbol is plotted if instability is expected. In addition, a curved line is plotted to show the parameters for "optimal" bunchlengthening in a cubic + quartic synchrotron potential. To the right of this curved line, double-hump bunches occur for which the analytic instability predictions may not be justified.

The instability symbols used are: −: parasitic coupled-bunch instability; |: coupled-dipole Robinson instability; *: coupled-quadrupole Robinson instability; #: fast dipole-quadrupole Robinson mode-coupling instability; c: M = ±1 coupled-bunch instability; /: equilibrium phase Robinson instability; \: zero-frequency coupled dipole-quadrupole Robinson instability.

For each case, an analytic instability plot is also shown in which the parasitic coupled-bunch instability is not considered. To test the accuracy of the instability predictions, 500,000-turn simulations were performed for bunches injected at the synchronous phase. Parasitic modes are not included in the simulations. A final energy spread that exceeds the natural value by more than 10% is taken to indicate the presence of instability, and is denoted by an "o" in figures describing simulations. A shift in phase of stable bunches by more than 2.35 times the rms bunch length is taken to signify that an equilibrium phase instability has previously occurred [3, 7], and is denoted by an "x". An instability where the bunch phase is unchanged and the energy spread is increased by less than 10% will not be detected by these criteria.

In addition, the bunchlengths are calculated for the case without a harmonic cavity, and for optimal bunchlengthening. We also note the frequency of the coupled-dipole Robinson mode, which is the frequency where phase noise on the beam is expected to be largest [3].

2. MAX-II with a 100-MHz/500-MHz RF system

Instability predictions for MAX-II from analytic formulas are shown in Figs. 1(a) for the case where parasitic coupled-bunch instability is considered, and in Fig. 1(b) for the case where parasitic modes are not considered. The parameters used are in Appendix A. The analytic modeling suggests that parasitic modes will be suppressed by Landau damping when the bunches are optimally lengthened. However, dipole-quadrupole mode coupling instability may affect optimal bunchlengthening for currents of 100–250 mA. Simulations shown in Fig. 1(c) are in approximate agreement with analytic modeling of Fig. 1(b). According to the simulations, optimally lengthened bunches are stable for ring currents exceeding 150 mA. This suggests that optimally lengthened bunches may be utilized for ring currents exceeding 150 mA, while partially lengthened bunches may be used at lower currents to suppress parasitic coupled bunch instabilities.

The coupled-dipole Robinson frequency is nearly independent of the harmonic cavity tuning angle for single-hump bunches, decreasing from 7.8 kHz at zero current to 2.5 kHz at a maximum ring current of 300 mA. The coupled-dipole Robinson frequency remains nearly constant when the harmonic cavity is tuned in because the excited RF sidebands cancel the potential-well distortion from the harmonic cavity; this behavior is evident when the dipole Robinson frequency is expressed by eq. (9) of Ref. [8].

Without a harmonic cavity, the calculated rms bunchlength is 57 ps. For optimal bunchlengthening by a passive harmonic cavity, the bunchlength depends upon the ring current. It ranges from 230 ps for a current of 100 mA to 176 ps for a current of 300 mA; therefore the bunch is lengthened by a factor of 3–4.

To model the presence of two superconducting wigglers, the synchronous voltage was increased from 140 kV to 180 kV. The analytic instability predictions and simulation results for this case are nearly identical to those in Fig. 1.

3. MAX-II with a 500-MHz/1500-MHz RF system

Instability predictions are shown in Fig. 2 for the existing MAX-II RF system with four 1500-MHz passive harmonic cavities. Parameters are in Appendix B. For currents exceeding ~120 mA, stable optimally lengthened bunches are predicted. However, overheating of the harmonic cavities prevents operation with optimally lengthened bunches [9]. Suppression of parasitic modes by tuning in the harmonic cavity is predicted, in agreement with observations. The coupled-dipole Robinson frequency is nearly independent of the harmonic cavity tuning angle for single-hump bunches, decreasing from 20 kHz at zero current to 8 kHz at a maximum ring current of 300 mA.

Without the harmonic cavities, the calculated rms bunchlength is 22 ps. For optimal bunchlengthening by four passive harmonic cavities, the bunchlength ranges from 75 ps for a current of 100 mA to 64 ps for a current of 300 mA; therefore the bunch is lengthened by a factor of 2.9–3.4.

For a ring current of 210 mA, the analytic code predicts that the coupled-dipole Robinson mode has a frequency of 10.1 kHz, independent of the harmonic-cavity tuning angle. The calculated damping rate of ~16 kHz indicates that this Robinson mode is highly damped. These predictions agree with the observation of a broad 10-kHz sideband of the 499.8 MHz rotation line, which remains fixed as the harmonic cavity is tuned in. Parasitic modes are expected to have a frequency near the rigid-dipole oscillation frequency ω_R [2]. This frequency is computed to decrease from 20.3 kHz to 13 kHz as the harmonic cavity voltage is increased to 120 kV (i.e., 30 kV/cavity [1], which is 60% of the voltage required for optimal bunchlengthening). Experimentally, the dominant sideband frequency of the 349.9-MHz rotation line decreased from ~20 kHz to 14 kHz, in approximate agreement.

4. MAX-III with a 100-MHz/500-MHz RF system

For MAX-III, the use of one harmonic cavity is modeled in Fig. (3), while two cavities are modeled in Fig. (4). Parameters are in Appendixes C and D. According to Figs. 3(a) and 4(a), stable operation with one harmonic cavity may be obtained for currents of 160–300 mA, while stable operation with two harmonic cavities may be obtained for currents of 100–300 mA. In simulations, stable optimally lengthened bunches required a current greater than 240 mA with one harmonic cavity, while a current exceeding 120 mA is sufficient for stable optimally lengthened bunches with two harmonic cavities. Thus, using two harmonic cavities should allow a longer Touschek lifetime to be maintained as the ring current decays below 240 mA.

The coupled-dipole Robinson frequency is nearly independent of the harmonic cavity tuning angle and ring current for single-hump bunches, equaling ~36 kHz.

Without a harmonic cavity, the calculated rms bunchlength is 92 ps. For optimal bunchlengthening by one passive harmonic cavity, the bunchlength ranges from 231 ps for a current of 100 mA to 223 ps for a current of 300 mA; therefore the bunch is lengthened by a factor of 2.4–2.5. For optimal bunchlengthening by two passive harmonic cavities, the bunchlength ranges from 224 ps for a current of 100 mA to 223 ps for a current of 300 mA; therefore the bunch is lengthened by a factor of 2.4.

5. MAX-IV with 100-MHz/500-MHz RF systems

For the proposed MAX-IV 1.5-GeV ring, the use of four fundamental cavities and one harmonic cavity is modeled in Fig. (5) for ring currents up to 800 mA. Parameters are in Appendix E. According to Fig. 5(a), parasitic coupled bunch instability is expected for single-hump or optimally lengthened bunches, due to insufficient Landau- and radiation- damping. Thus, effective suppression of parasitic RF-cavity modes or a longitudinal feedback system may be required. If parasitic coupled bunch instability is thereby suppressed, simulations indicate that optimally lengthened bunches are stable for currents of 200–400 mA. For currents of 400–600 mA, near-optimal bunchlengthening is stable, so that a large increase of the Touschek lifetime should be possible for currents of 200-600 mA. The coupled-dipole Robinson frequency is nearly independent of the harmonic cavity tuning angle for single-hump bunches, decreasing from 2 kHz at zero current to 330 Hz at a ring current of 600 mA.

Without a harmonic cavity, the calculated rms bunchlength is 28.6 ps. For optimal bunchlengthening by the passive harmonic cavity, the bunchlength ranges from 142 ps for a current of 200 mA to 124 ps for a current of 600 mA; therefore the bunch is lengthened by a factor of 4.3–5.0.

For the proposed MAX-IV 3-GeV ring, the use of ten fundamental cavities and two harmonic cavities is modeled in Fig. (6) for ring currents up to 800 mA. Parameters are in Appendix F. Suppression of parasitic coupled bunch instability is expected, but the RF system is susceptible to the equilibrium phase instability (also called the zero-frequency Robinson instability) for currents exceeding ~600 mA. The equilibrium phase instability onsets at lower currents when the harmonic cavity is tuned in. Stable optimally lengthened bunches are observed in simulations for currents of 280–500 mA. The coupled-dipole Robinson frequency depends slightly upon the harmonic cavity tuning angle for single-hump bunches, decreasing from 3 kHz at zero current to a range of 330–410 Hz at a ring current of 600 mA.

Without a harmonic cavity, the calculated rms bunchlength is 39 ps. For optimal bunchlengthening by the passive harmonic cavities, the calculated bunchlength ranges from 180 ps for a current of 200 mA to 147 ps for a current of 600 mA; therefore the bunch is lengthened by a factor of 3.8–4.6.

For ring currents exceeding 420 mA, the coupled-dipole Robinson frequency is below 500 Hz for the 1.5-GeV ring, and below 1 kHz for the 3-GeV ring. Because the beam's phase noise is expected to have a large response at the coupled-dipole Robinson frequency [3], it may be necessary to minimize power-supply noise at frequencies below 1 kHz for quiet ring operation.

6. Summary

For harmonic-cavity operation at MAXlab, instability modeling was performed for several rings using analytic formulas and simulations. For the existing MAX-II RF system, the predicted frequencies of the coupled-dipole Robinson mode and parasitic coupled-bunch modes are in approximate agreement with observation.

Except for MAX-IV operation at 1.5 GeV, optimally lengthened bunches are predicted to suppress parasitic coupled bunch instabilities. Typically, "double-hump" bunches are susceptible to coupled-quadrupole Robinson instability, while optimal bunchlengthening of low-current bunches is destabilized by the coupled-dipole Robinson instability. Dipole-quadrupole fast mode-coupling Robinson instability is also predicted to occur.

Acknowledgments

The author thanks M. Eriksson and Å. Andersson for ring parameters and stimulating discussions.

References

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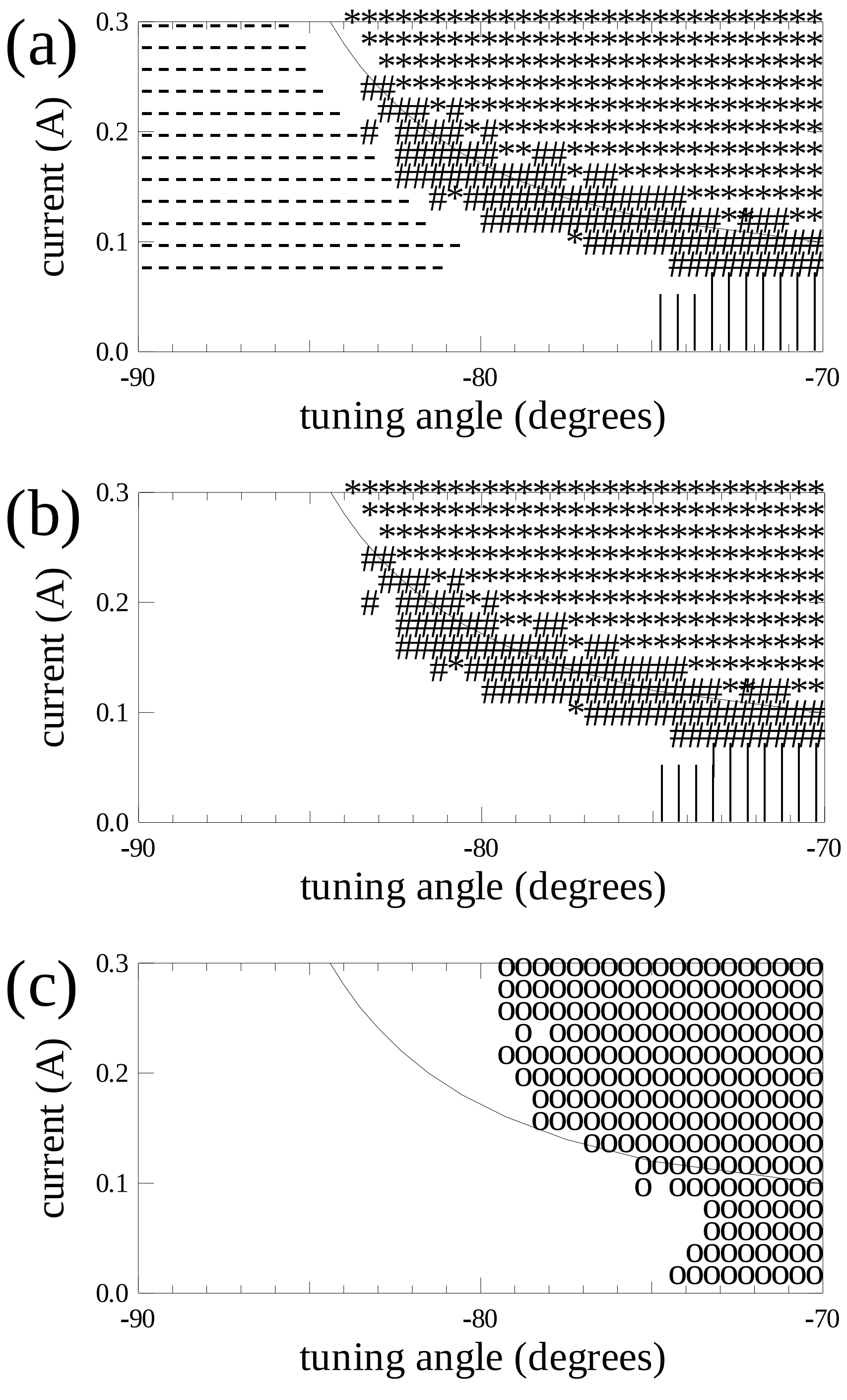

Figure 1. Instability modeling for MAX-II with a 100-MHz/500-MHz RF system. A solid curve shows the parameters for optimal bunch lengthening. To the left of this curve, the bunches are "understretched" single-hump bunches. To the right, the bunches are "overstretched" double-hump bunches. (a) Analytic instability predictions including parasitic coupled bunch instability. (b) Analytic instability predictions for no parasitic modes. (c) Instabilities observed in 500,000-turn simulations with no parasitic modes.

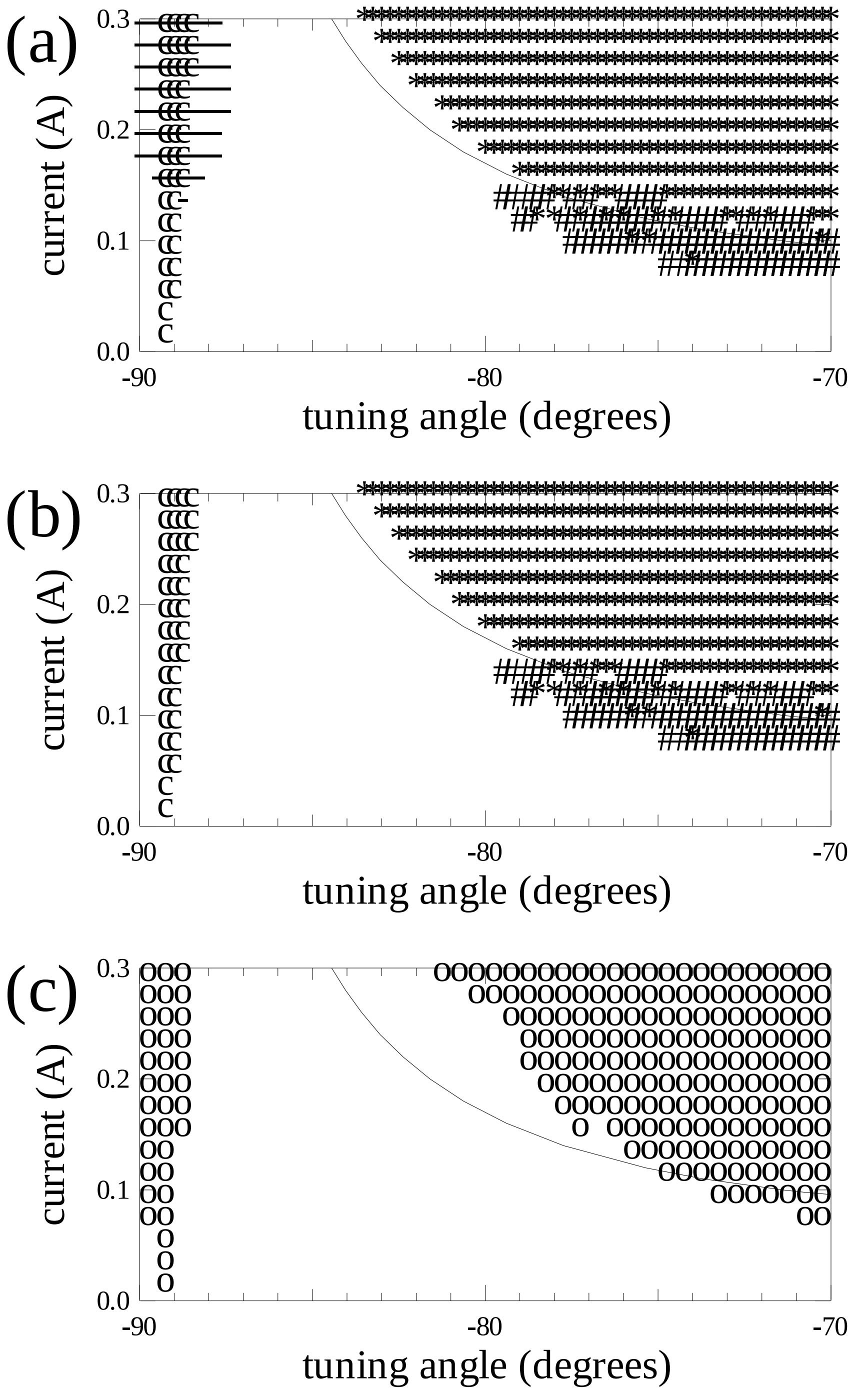

Figure 2. Instability modeling for MAX-II with a 500-MHz/1500-MHz RF system. A solid curve shows the parameters for optimal bunch lengthening. (a) Analytic instability predictions including parasitic coupled bunch instability. (b) Analytic instability predictions for no parasitic modes. (c) Instabilities observed in 500,000-turn simulations with no parasitic modes.

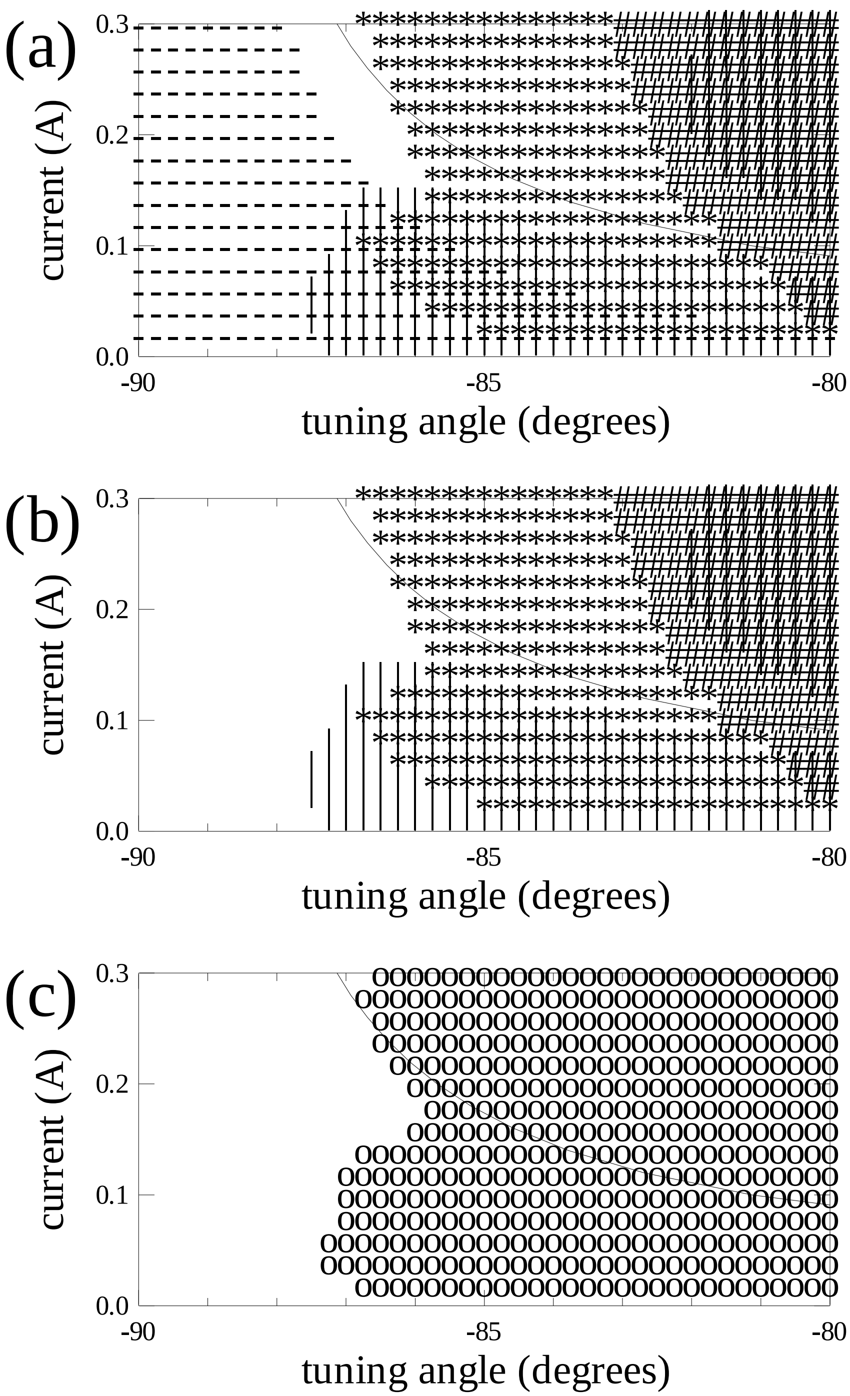

Figure 3. Instability modeling for MAX-III with a 100-MHz/500-MHz RF system that uses one harmonic cavity. A solid curve shows the parameters for optimal bunch lengthening. (a) Analytic instability predictions including parasitic coupled bunch instability. (b) Analytic instability predictions for no parasitic modes. (c) Instabilities observed in 500,000-turn simulations with no parasitic modes.

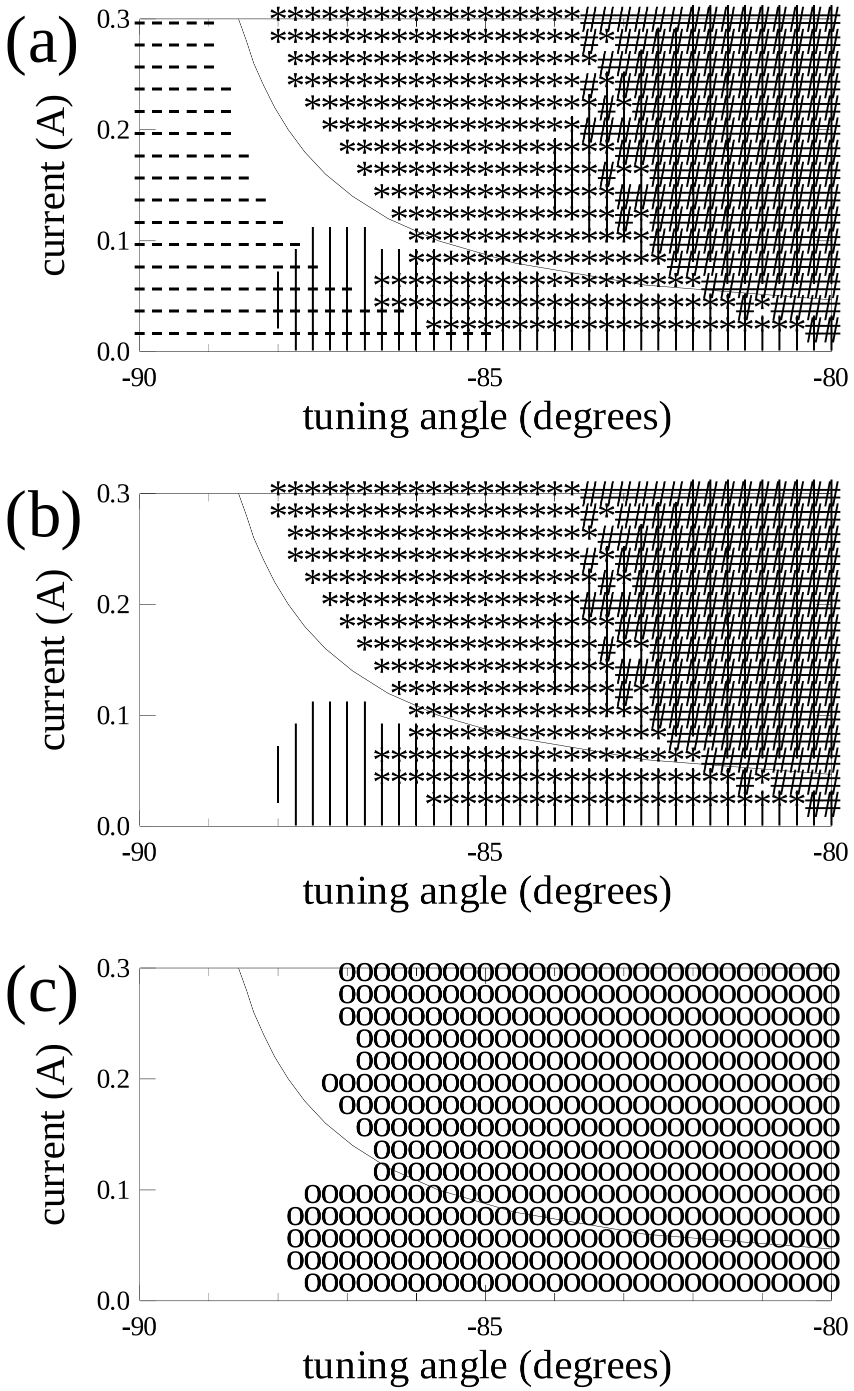

Figure 4. Instability modeling for MAX-III with a 100-MHz/500-MHz RF system that uses two harmonic cavities. A solid curve shows the parameters for optimal bunch lengthening. (a) Analytic instability predictions including parasitic coupled bunch instability. (b) Analytic instability predictions for no parasitic modes. (c) Instabilities observed in 500,000-turn simulations with no parasitic modes.

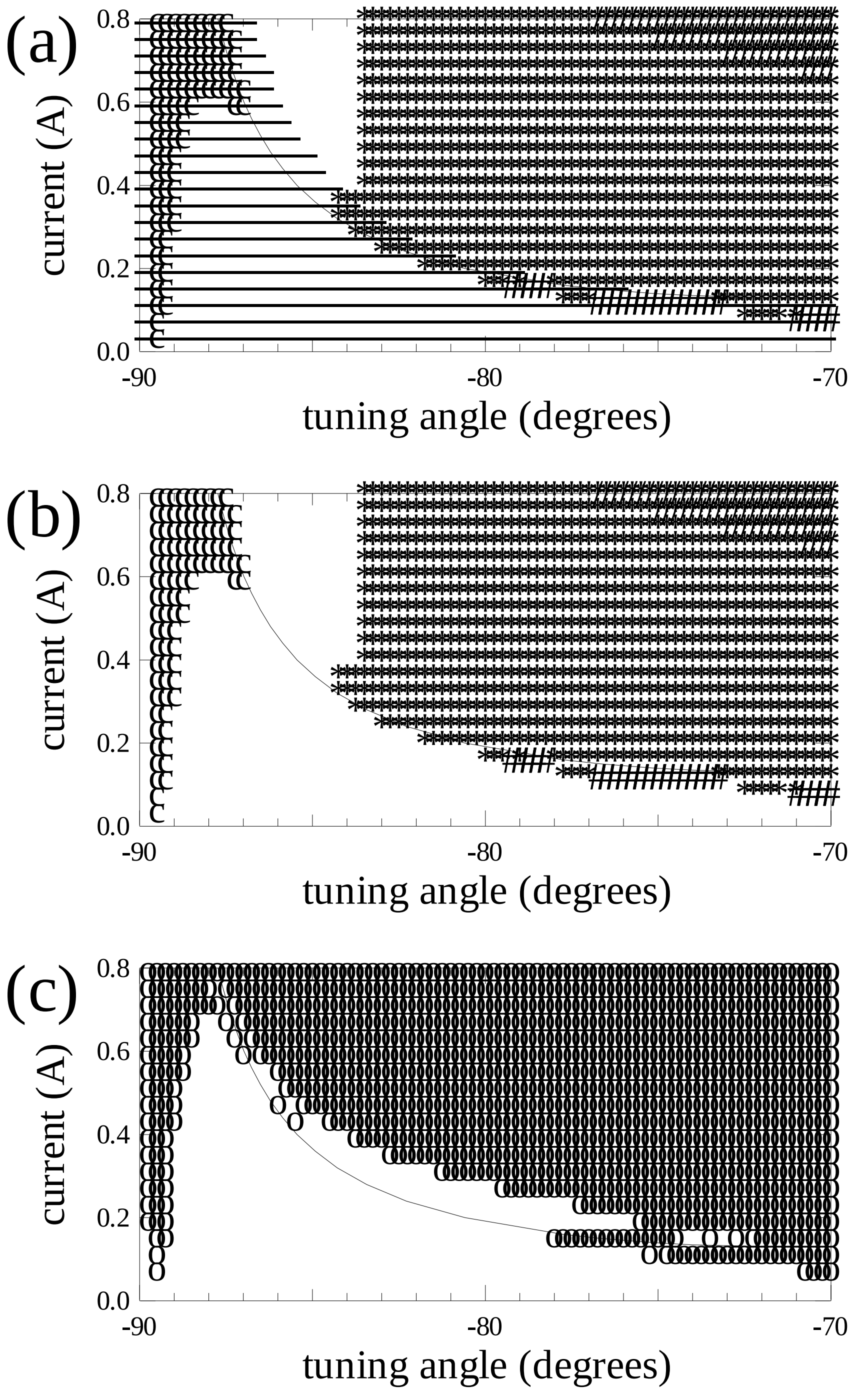

Figure 5. Instability modeling for MAX-IV, 1.5 GeV with a 100-MHz/500-MHz RF system that uses four fundamental cavities and one harmonic cavity. A solid curve shows the parameters for optimal bunch lengthening. (a) Analytic instability predictions including parasitic coupled bunch instability. (b) Analytic instability predictions for no parasitic modes. (c) Instabilities observed in 500,000-turn simulations with no parasitic modes.

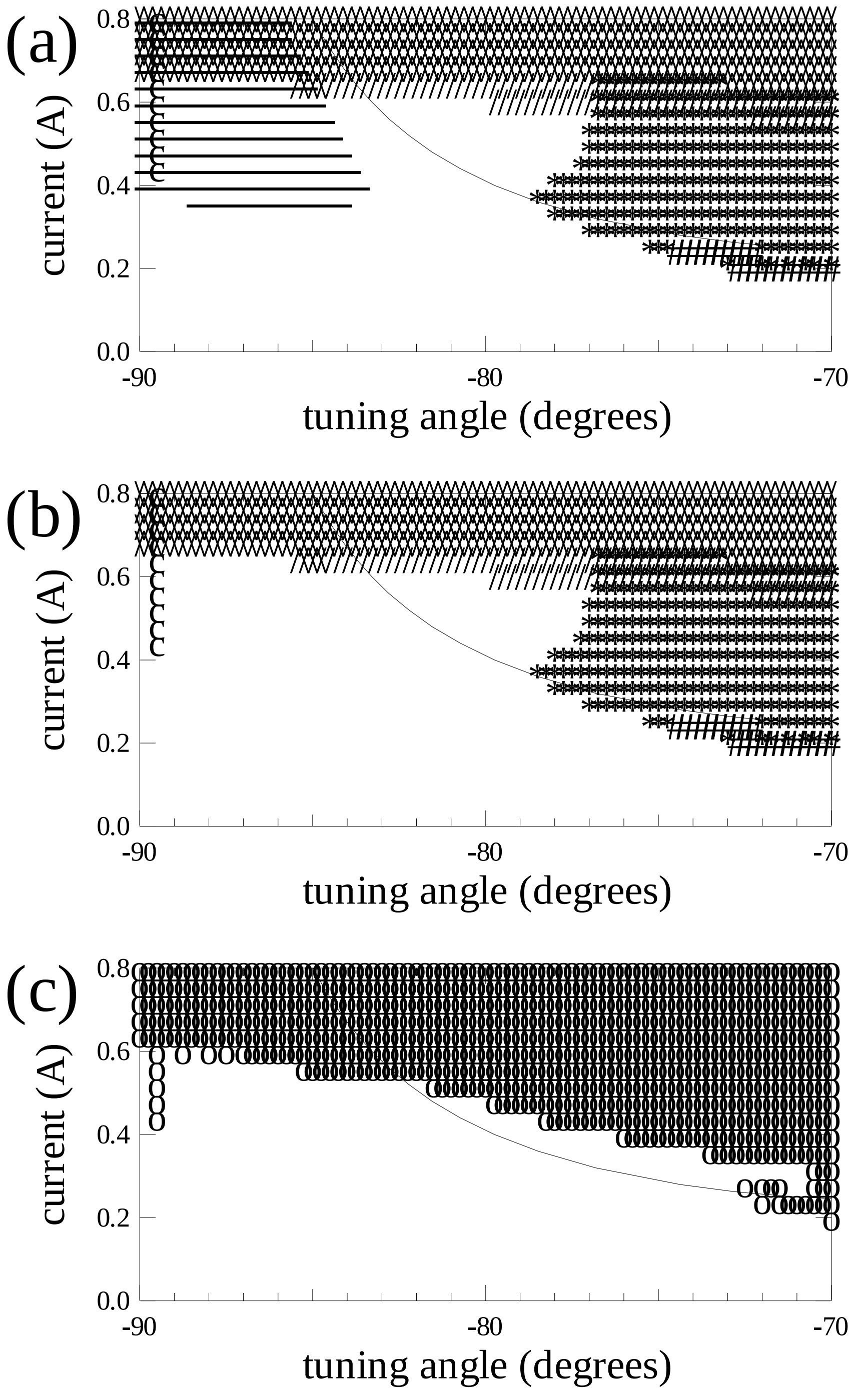

Figure 6. Instability modeling for MAX-IV, 3 GeV with a 100-MHz/500-MHz RF system that uses ten fundamental cavities and two harmonic cavities. A solid curve shows the parameters for optimal bunch lengthening. (a) Analytic instability predictions including parasitic coupled bunch instability. (b) Analytic instability predictions for no parasitic modes. (c) Instabilities observed in 500,000-turn simulations with no parasitic modes.

Appendix A. Input file with parameters for MAX-II with a 100-MHz/500-MHz RF system.

```
C data for MAXII, nu=5, updated at MAXlab 2/16/04
450.e3  ! vt1 = Cavity 1 peak voltage (volts)
3.      ! beta1 = Cav. 1 RF coupling coefficient
19000.  ! q1o = Cavity 1 quality factor (unloaded)
4.8e6   ! r1o = Cavity 1 impedance at resonance (unloaded) (ohms)
0.      ! loadangle1: generator current lags cavity voltage by loadangle1 (deg)
0.004   ! alpha = momentum compaction
3.0e-7  ! To = recirculation time (s)
6.28e8  ! wg = RF angular frequency (rad/s)
1.5e9   ! Ee = electron energy/charge, i.e. energy in eV
7.e-4   ! sigmae = relative energy spread from synchrotron radiation
140.e3  ! vs = energy loss/revolution from synchrotron radiation (volts)
3.2e-3  ! t_L = longitudinal radiation damping time (seconds)
5       ! nu = Cavity 2 harmonic number
0.      ! beta2 = Cav. 2 RF coupling coefficient
24000.  ! q2o = Cavity 2 quality factor (unloaded)
1.7e6   ! r2o = Cav. 2 resonant impedance (unloaded)
10.e3   ! zcb = parasitic mode impedance (ohms)
6.28e9  ! wcb = parasitic mode angular frequency (radian/s)
0.020   ! imin = minimum ring current to be modeled (A)
0.300   ! imax = maximum ring current to be modeled (A)
0.020   ! delta_i = ring current increment between calculations (A)
-89.75  ! phi2_min = minimum Landau tuning angle to be modeled (degrees)
-69.75  ! phi2_max = maximum Landau tuning angle to be modeled (degrees)
0.5     ! delta_phi2 = Landau tuning angle increment between calculations
1.      ! damp=1: consider Landau damping of Robinson modes, 0: w/o
0.      ! tfeedback: dipole-mode damping time (seconds); enter 0. for no feedback
1       ! Nturn_ebar: number of turns to measure energy offset for feedback
30      ! M = number of macroparticles per bucket
30      ! Nbucket = number of buckets, including empty buckets
30      ! Nbunch = number of consecutive buckets in bunch train
500000  ! Nturn_max = number of turns to track
100     ! Nturnwrite=number of turns to skip between writing output of passive_15.for
```

Appendix B. Input file with parameters for MAX-II with the existing 500-MHz/1500-MHz RF system.

```
C data for MAXII 500 MHz system, nu=3, 2/17/04
600.e3  ! vt1 = Cavity 1 peak voltage (volts)
3.      ! beta1 = Cav. 1 RF coupling coefficient
40000.  ! q1o = Cavity 1 quality factor (unloaded)
10.e6   ! r1o = Cavity 1 impedance at resonance (unloaded) (ohms)
-10.    ! loadangle1: generator current lags cavity voltage by loadangle1 (deg)
0.004   ! alpha = momentum compaction
3.0e-7  ! To = recirculation time (s)
3.142e9 ! wg = RF angular frequency (rad/s)
1.5e9   ! Ee = electron energy/charge, i.e. energy in eV
7.e-4   ! sigmae = relative energy spread from synchrotron radiation
140.e3  ! vs = energy loss/revolution from synchrotron radiation (volts)
3.2e-3  ! t_L = longitudinal radiation damping time (seconds)
3       ! nu = Cavity 2 harmonic number
0.      ! beta2 = Cav. 2 RF coupling coefficient
16000.  ! q2o = Cavity 2 quality factor (unloaded)
4.0e6   ! r2o = Cav. 2 resonant impedance (unloaded)
10.e3   ! zcb = parasitic mode impedance (ohms)
6.28e9  ! wcb = parasitic mode angular frequency (radian/s)
0.020   ! imin = minimum ring current to be modeled (A)
0.300   ! imax = maximum ring current to be modeled (A)
0.020   ! delta_i = ring current increment between calculations (A)
-89.75  ! phi2_min = minimum Landau tuning angle to be modeled (degrees)
-70.    ! phi2_max = maximum Landau tuning angle to be modeled (degrees)
0.5     ! delta_phi2 = Landau tuning angle increment between calculations
1.      ! damp=1: consider Landau damping of Robinson modes, 0: w/o
0.      ! tfeedback: dipole-mode damping time (seconds); enter 0. for no feedback
1       ! Nturn_ebar: number of turns to measure energy offset for feedback
6       ! M = number of macroparticles per bucket
150     ! Nbucket = number of buckets, including empty buckets
150     ! Nbunch = number of consecutive buckets in bunch train
500000  ! Nturn_max = number of turns to track
100     ! Nturnwrite=number of turns to skip between writing output of passive_15.for
```

Appendix C. Input file with parameters for MAX-III with a 100-MHz/500-MHz RF system that uses one harmonic cavity.

```
C data for MAXIII, 5th harmonic cavity, updated at MAXlab 2/17/04
200.e3  ! vt1 = Cavity 1 peak voltage (volts)
2.      ! beta1 = Cav. 1 RF coupling coefficient
19000.  ! q1o = Cavity 1 quality factor (unloaded)
1.6e6   ! r1o = Cavity 1 impedance at resonance (unloaded) (ohms)
0.      ! loadangle1: generator current lags cavity voltage by loadangle1 (deg)
0.035   ! alpha = momentum compaction
1.2e-7  ! To = recirculation time (s)
6.28e8  ! wg = RF angular frequency (rad/s)
0.700e9 ! Ee = electron energy/charge, i.e. energy in eV
6.e-4   ! sigmae = relative energy spread from synchrotron radiation
13.e3   ! vs = energy loss/revolution from synchrotron radiation (volts)
11.e-3  ! t_L = longitudinal radiation damping time (seconds)
5       ! nu = Cavity 2 harmonic number
0.      ! beta2 = Cav. 2 RF coupling coefficient
24000.  ! q2o = Cavity 2 quality factor (unloaded)
1.7e6   ! r2o = Cav. 2 resonant impedance (unloaded)
10.e3   ! zcb = parasitic mode impedance (ohms)
6.28e9  ! wcb = parasitic mode angular frequency (radian/s)
0.020   ! imin = minimum ring current to be modeled (A)
0.300   ! imax = maximum ring current to be modeled (A)
0.020   ! delta_i = ring current increment between calculations (A)
-90.    ! phi2_min = minimum Landau tuning angle to be modeled (degrees)
-80.    ! phi2_max = maximum Landau tuning angle to be modeled (degrees)
0.25    ! delta_phi2 = Landau tuning angle increment between calculations (degrees)
1.      ! damp=1: consider Landau damping of Robinson modes, 0: w/o
0.      ! tfeedback: dipole-mode damping time (seconds); enter 0. for no feedback
1       ! Nturn_ebar: number of turns to measure energy offset for feedback
75      ! M = number of macroparticles per bucket
12      ! Nbucket = number of buckets, including empty buckets
12      ! Nbunch = number of consecutive buckets in bunch train
500000  ! Nturn_max = number of turns to track
100     ! Nturnwrite=number of turns to skip between writing output of passive_15.for
```

Appendix D. Input file with parameters for MAX-III with a 100-MHz/500-MHz RF system that uses two harmonic cavities.

```
C data for MAXIII, two 5th harmonic cavities, updated at MAXlab 2/17/04
200.e3  ! vt1 = Cavity 1 peak voltage (volts)
2.      ! beta1 = Cav. 1 RF coupling coefficient
19000.  ! q1o = Cavity 1 quality factor (unloaded)
1.6e6   ! r1o = Cavity 1 impedance at resonance (unloaded) (ohms)
0.      ! loadangle1: generator current lags cavity voltage by loadangle1 (deg)
0.035   ! alpha = momentum compaction
1.2e-7  ! To = recirculation time (s)
6.28e8  ! wg = RF angular frequency (rad/s)
0.700e9 ! Ee = electron energy/charge, i.e. energy in eV
6.e-4   ! sigmae = relative energy spread from synchrotron radiation
13.e3   ! vs = energy loss/revolution from synchrotron radiation (volts)
11.e-3  ! t_L = longitudinal radiation damping time (seconds)
5       ! nu = Cavity 2 harmonic number
0.      ! beta2 = Cav. 2 RF coupling coefficient
24000.  ! q2o = Cavity 2 quality factor (unloaded)
3.4e6   ! r2o = Cav. 2 resonant impedance (unloaded)
10.e3   ! zcb = parasitic mode impedance (ohms)
6.28e9  ! wcb = parasitic mode angular frequency (radian/s)
0.020   ! imin = minimum ring current to be modeled (A)
0.300   ! imax = maximum ring current to be modeled (A)
0.020   ! delta_i = ring current increment between calculations (A)
-90.    ! phi2_min = minimum Landau tuning angle to be modeled (degrees)
-80.    ! phi2_max = maximum Landau tuning angle to be modeled (degrees)
0.25    ! delta_phi2 = Landau tuning angle increment between calculations (degrees)
1.      ! damp=1: consider Landau damping of Robinson modes, 0: w/o
0.      ! tfeedback: dipole-mode damping time (seconds); enter 0. for no feedback
1       ! Nturn_ebar: number of turns to measure energy offset for feedback
75      ! M = number of macroparticles per bucket
12      ! Nbucket = number of buckets, including empty buckets
12      ! Nbunch = number of consecutive buckets in bunch train
500000  ! Nturn_max = number of turns to track
100     ! Nturnwrite=number of turns to skip between writing output of passive_15.for
```

Appendix E. Input file with parameters for MAX-IV, 1.5 GeV with a 100-MHz/500-MHz RF system that uses four fundamental cavities and one harmonic cavity.

```
C data for MAXIV-1.5 GeV, nu=5, updated at MAXlab, 2/20/04
500.e3  ! vt1 = Cavity 1 peak voltage (volts)
2.      ! beta1 = Cav. 1 RF coupling coefficient
19000.  ! q1o = Cavity 1 quality factor (unloaded)
6.8e6   ! r1o = Cavity 1 impedance at resonance (unloaded) (ohms) for 4 cavities
0.      ! loadangle1: generator current lags cavity voltage by loadangle1 (deg)
0.000738 ! alpha = momentum compaction
9.5e-7  ! To = recirculation time (s)
6.28e8  ! wg = RF angular frequency (rad/s)
1.5e9   ! Ee = electron energy/charge, i.e. energy in eV
4.927e-4 ! sigmae = relative energy spread from synchrotron radiation
42.2e3   ! vs = energy loss/revolution from synchrotron radiation (volts)
51.78e-3 ! t_L = longitudinal radiation damping time (seconds)
5       ! nu = Cavity 2 harmonic number
0.      ! beta2 = Cav. 2 RF coupling coefficient
24000.  ! q2o = Cavity 2 quality factor (unloaded)
1.7e6   ! r2o = Cav. 2 resonant impedance (unloaded) for 1 cavity
10.e3   ! zcb = parasitic mode impedance (ohms)
6.28e9  ! wcb = parasitic mode angular frequency (radian/s)
0.040   ! imin = minimum ring current to be calculated (A)
0.800   ! imax = maximum ring current to be calculated (A)
0.040   ! delta_i = ring current increment between calculations (A)
-90.    ! phi2_min = minimum Landau tuning angle to be calculated (degrees)
-70.    ! phi2_max = maximum Landau tuning angle to be calculated (degrees)
0.25    ! delta_phi2 = Landau tuning angle increment between calculations (degrees)
1.      ! damp=1: consider Landau damping of Robinson modes, 0: w/o
0.      ! t_feedback: dipole-mode damping time (seconds); enter 0. for no feedback
1       ! Nturn_ebar: number of turns to measure energy offset for feedback
10      ! M = number of macroparticles per bucket
95      ! Nbucket = number of buckets, including empty buckets
95      ! Nbunch = number of consecutive buckets in bunch train
500000  ! Nturn_max = number of turns to track
100     ! Nturnwrite=number of turns to skip between writing output of passive_15.for
```

Appendix F. Input file with parameters for MAX-IV, 3 GeV with a 100-MHz/500-MHz RF system that uses ten fundamental cavities and two harmonic cavities.

```
C data for MAXIV-3GeV, nu=5, 2 Landau cavities, updated at MAXlab, 2/20/04
2250.e3 ! vt1 = Cavity 1 peak voltage (volts)
2.      ! beta1 = Cav. 1 RF coupling coefficient
19000.  ! q1o = Cavity 1 quality factor (unloaded)
17.e6   ! r1o = Cavity 1 impedance at resonance (unloaded) (ohms) for 10 cavities
0.      ! loadangle1: generator current lags cavity voltage by loadangle1 (deg)
0.000738 ! alpha = momentum compaction
9.5e-7  ! To = recirculation time (s)
6.28e8  ! wg = RF angular frequency (rad/s)
3.0e9   ! Ee = electron energy/charge, i.e. energy in eV
9.854e-4 ! sigmae = relative energy spread from synchrotron radiation
675.1e3 ! vs = energy loss/revolution from synchrotron radiation (volts)
6.47e-3 ! t_L = longitudinal radiation damping time (seconds)
5       ! nu = Cavity 2 harmonic number
0.      ! beta2 = Cav. 2 RF coupling coefficient
24000.  ! q2o = Cavity 2 quality factor (unloaded)
3.4e6   ! r2o = Cav. 2 resonant impedance (unloaded) for 2 cavities
10.e3   ! zcb = parasitic mode impedance (ohms)
6.28e9  ! wcb = parasitic mode angular frequency (radian/s)
0.040   ! imin = minimum ring current to be calculated (A)
0.800   ! imax = maximum ring current to be calculated (A)
0.040   ! delta_i = ring current increment between calculations (A)
-90.    ! phi2_min = minimum Landau tuning angle to be calculated (degrees)
-70.    ! phi2_max = maximum Landau tuning angle to be calculated (degrees)
0.25    ! delta_phi2 = Landau tuning angle increment between calculations (degrees)
1.      ! damp=1: consider Landau damping of Robinson modes, 0: w/o
0.      ! t_feedback: dipole-mode damping time (seconds); enter 0. for no feedback
1       ! Nturn_ebar: number of turns to measure energy offset for feedback
10      ! M = number of macroparticles per bucket
95      ! Nbucket = number of buckets, including empty buckets
95      ! Nbunch = number of consecutive buckets in bunch train
500000  ! Nturn_max = number of turns to track
100     ! Nturnwrite=number of turns to skip between writing output of passive_15.for
```