Documentation for vlasov, version 0.1 *

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Abstract

This paper describes how to use the code vlasov, which implements the computation of multibunch frequencies and growth rates when the effects of multibunch mode coupling are included. The theory behind this code is described in [BR95a, BR95b, Ber96]. This paper also describes the algorithm used to compute the modes, and the approximations made.

1 Running the Code

The program modes00 will create a binary file output file from the input file described in section 2. To view this output, use the program plot00.

1.1 modes00

The syntax for running modes00 is simply

```
modes00 file.in file.out
```

where file.in is the input file described in section 2, and file.out is a binary file containing the computed modes. Note that the program will exit if file.out already exists.

1.2 plot00

To run plot00 to make a plot of the modes, type

```
plot00 file.out file.xmgr
```

where file.out is the output file generated from modes00, and file.xmgr is a file which can be given to the program xmgr to produce a plot of the modes. Note that the program will exit if file.xmgr already exists. To load the plot into xmgr, say

```
xmgr file.xmgr
```

When running plot00, you will be prompted for the type of plot that you want. The opening menu will look like:

```
0: Exit
1: Single current
2: Modes vs. current, real
3: Modes vs. current, imag
4: Modes vs. current, real, one mode set
5: Modes vs. current, imag, one mode set
6: Single current, for publication
7: Modes vs. current, real, for publication
8: Modes vs. current, imag, for publication
9: Modes vs. current, real, one mode set, for publication
10: Modes vs. current, imag, one mode set, for publication
Enter a number:
```

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Figure 1: Output from "Single current" and "Absolute value of imaginary part."

In general, options 1, 2, and 5 are the most useful. The corresponding "for publication" options are attempts to produce a plot that will satisfy Physical Review.

If you select option 1, you will be prompted for another choice:

1. Absolute value of imaginary part
2. Absolute value of shift
3. Positive imaginary part

Enter choice:

Option 1 will give you a plot similar to figure 1. Option 2 will give you a plot similar to figure 2. This is useful for the estimating of Landau damping thresholds. Option 3 will give you a plot similar to figure 3. In all cases you are prompted for a damping rate, which will give a dashed line on the resulting plots.

If you selected option 2 from the main menu, "Modes vs. current, real," then a plot will be produced similar to figure 4. The plot shows the real parts of the frequencies for all the modes. If you selected option 3, "Modes vs. current, imag," then a plot will be produced similar to figure 5. This shows the imaginary parts of the frequencies for all the modes. As you can see, this plot is often not particularly useful, except in the case of a single bunch ($M = 1$). It is generally more useful to plot the imaginary parts of specific modes. This is done through option 5, "Modes vs. current, imag, one mode set." In addition to the

Figure 2: Output from “Single current” and “Absolute value of shift.”

usual prompts, you will also be prompted for a mode number. The current method of numbering these is a bit cryptic. The mode number you are prompted for should be the value of $(n + n')/2$ for that mode (these values are described in [Ber96]; see equation (4.79)). For a non-radial mode, if the zero-current frequency is $\omega_y \pm m\omega_s$, then m is the number you specify. However, for a radial mode, the number you specify is $m + 2k$, where k is the order of the radial mode. For instance, for the first $m = 1$ radial mode, you would specify 3. If necessary, the program will then prompt you for the azimuthal offset. This is always the value of m . A plot will be produced that is similar to figure 6.

2 Input Format

The input file for the program consists of several keywords followed by values. The keywords must be typed exactly: *case does matter!* The order of the keywords is irrelevant. The keywords may be followed by one or more values, depending on the keyword. Those values may appear anywhere after the keyword, even on the next line. They are separated from one another by any combination of spaces, tabs, and end-of-line characters.

Figure 3: Output from “Single current” and “Positive imaginary part—.”

2.1 Parameters

All the values described in this section are required, unless otherwise indicated. Just to be clear, the keywords do not contain periods; that’s just my punctuation in this paper.

Momentum_Compaction. This is followed by a single number. This is the negative of η_c as defined in [Wie93].

It should be positive above transition. The program will also accept “eta.c.” This part is optional.

Betatron_Tune. This is followed by a single number. The program will also accept “nu.beta.”

Synchrotron_Tune. This is followed by a single number. The program will also accept “nu.s.”

Bunch_Length. This is followed by a single number. It is the bunch length divided by the circumference of the ring. The program will also accept “sigma.l.”

Energy. This is followed by a single number. It is the energy in eV. The program will also accept “E.0.”

Current. This is followed by two numbers: the maximum current, and the number of current points to plot. The program will also accept “I.”

Figure 4: Output from "Modes vs. current, real."

Emittance. This followed by a single number: the transverse emittance of the beam divided by the circumference of the ring. Emittance is defined such that $\sigma_y = \sqrt{\epsilon_y \beta_y}$. The program will also accept "epsilon." This part is optional.

n. This is followed by two positive integers: the minimum and maximum azimuthal mode numbers. Note that the radial modes which have the same form factors as some non-radial modes are always computed together with those modes. So, for instance, including an azimuthal mode number of 3 always include the $m = 1$ radial modes as well. Currently, the program won't work unless the minimum mode number is 0.

p. This is followed by three integers: the minimum mode index offset, the step in that offset, and the total number of offsets which will be computed.

M. This is followed by one positive integer, the number of symmetric bunches to do the computation for. Currently the program only works with symmetric bunches.

Chromaticity. This is followed by one number, the chromaticity. This part is optional.

Transverse. What follows this is a description of the transverse impedance. This will be described in a separate section. This part is ended by the word "END." This part is optional.

Figure 5: Output from "Modes vs. current, imag."

Transverse.Feedback. What follows this is a description of the transverse feedback system. This will be described in a separate section. This part is ended by the word "END." This part is optional.

2.2 Transverse Impedance

Between the **Transverse** and **END** keywords, there are a sequence of keywords which indicate what type of transverse impedance you are using. Each of these keywords will be followed by one or more values. One of these values will be the strength of the impedance. This value will be in units of Ohms. This value is the actual impedance multiplied by the average transverse β -function over the impedance. The user must compute this product and use it in the appropriate place. Finally, all frequencies used are the actual frequency divided by the revolution frequency.

Resonator.TI. There are three values, ω_R , Q , and R , where the impedance is given by

$$\frac{R}{\omega/\omega_R + iQ(1 - \omega^2/\omega_R^2)} \quad (1)$$

Figure 6: Output from "Modes vs. current, imag, one mode set."

ResistiveWall.TI. There is one value, R , where the impedance is given by the formula

$$-i\sqrt{2}\frac{R}{\sqrt{-i\omega/\omega_0}}. \quad (2)$$

Here ω_0 is the revolution frequency. Thus, R is the real or imaginary part of the impedance at ω_0 .

Inductive.TI. There is only one value, L . The impedance is $-iL$, a constant.

CavityTail.TI. There are three values, the real and imaginary parts of ω_R , followed by R , where the impedance is given by

$$i\frac{R\omega_0}{\omega} \left(\frac{1}{\sqrt{1+\omega/\omega_R^*}} - \frac{1}{\sqrt{1-\omega/\omega_R}} \right). \quad (3)$$

Note that the imaginary part of ω_R should be negative, and the real part of ω_R should be positive.

SingleBranch.TI. There are two parameters, R and ω_C , where the impedance is given by

$$\frac{-iR}{(1-i\omega/\omega_C)^{3/2}}. \quad (4)$$

2.3 Transverse Feedback

Between the `Transverse_Feedback` and `END` keywords, there are a sequence of keywords which indicate what type of transverse impedance you are using. Each of these keywords will be followed by one or more values. One of these values will be the gain of the feedback. This value will be in units of Ohms, and should take into account the β -functions at the pickup and the kicker. Also, every feedback device will have a distance between the pickup and kicker associated with it. This will be the pickup to kicker distance multiplied by 2π and divided by the ring circumference. Finally, all frequencies used are the actual frequency divided by the revolution frequency.

`LowPass_TF`. There are three parameters: the gain A , a half-bandwidth ω_C , and the pickup to kicker distance. The model used has a response of

$$\frac{iA}{1 - i\omega/\omega_C} \quad (5)$$

`Butterworth2_TF` There are three parameters, the same as those for `LowPass_TF`, except the model has a response like

$$\frac{iAe^{-i\sqrt{2}\omega/\omega_C}}{1 - i\sqrt{2}\omega/\omega_C - \omega^2/\omega_C^2} \quad (6)$$

This is a second-order Butterworth filter, with the time delay removed.

2.4 Example

Consider the following example: A ring has the following parameters:

f_{rf}	476 MHz
h_{rf}	3492
η_C	0.00123208786107
L	2199.318 m
ν_y	36.64
ν_s	.03362246
σ_t	1 cm
E	3.109 GeV
ϵ_y	2.57 nm-rad
M	1746
I	2.254 A

The resistive wall impedance consists of two parts: a section with a total impedance of 902 k Ω /m at the frequency f_{rf}/h_{rf} with an average β_y of 16.3061 m, and a section with a total impedance of 560 k Ω /m with an average β_y of 22.1851 m. There is an inductive impedance of 65.76 k Ω /m, which rolls off with a characteristic frequency near 24.1 GHz. Its average β_y is 18.3647 m. The high-frequency tails due to the cavities are modelled using equation (3), with $\omega_R = 2.4 - i1.34722$ GHz and $R = 15.7985$ k Ω /m per cavity. There are 8 cavities, with an average β_y of 17.8720 m. Those same cavities have the following higher-order modes:

f_R (GHz)	Q	R (k Ω /m)
0.792	115	34.916
1.063	27	16.911
1.133	54	0.162
1.202	871	10.135
1.327	611	58.328
1.420	1138	160.689
1.542	92	2.508
1.595	145	7.777
1.676	783	153.796
1.723	446	0.177
1.749	1317	2.414

The following input file describes this ring:

```

Momentum_Compaction      0.00123208786107
Betatron_Tune             36.64
Synchrotron_Tune         0.03362246
Bunch_Length             4.5468e-6
Energy                   3.109e9
Emittance                 1.1685e-12
M                          1746
Current                   2.254 1
n                          0 3
p                          0 1 1746
Transverse
ResistiveWall_TI          2.71e7
SingleBranch_TI           1.208e6 1.77e5
CavityTail_TI             17606.7 -9883.39      2.27382e9
Resonator_TI      5810.21848739496      115      4992150.016
Resonator_TI      7798.31092436975      27      2417867.136
Resonator_TI      8311.84033613445      54      23162.112
Resonator_TI      8818.03361344538      871     1449061.76
Resonator_TI      9735.05042016807      611     8339504.128
Resonator_TI      10417.3109243697      1138    22974670.464
Resonator_TI      11312.3193277311      92      358583.808
Resonator_TI      11701.1344537815      145     1111924.352
Resonator_TI      12295.3613445378      783     21989136.896
Resonator_TI      12640.1596638655      446     25306.752
Resonator_TI      12830.8991596639      1317    345144.064
END

```

This input file will give a file with the $m = 0$, $m = 1$, $m = 2$, $m = 3$, $m = 0$ radial, and $m = 1$ radial modes at a single current of 2.254 A, for all 1746 multibunch modes. If you want the modes for several currents, change the Current line to

```
Current 25 100
```

which would find values for the modes for 100 evenly spaced currents up to 25 A.

To add a 250 MHz full-bandwidth damping feedback system, one would add the following lines

```

Transverse_Feedback
Butterworth2_TF 1e+07 971 0.0428710787882
END

```

3 Algorithm and Approximations

This code uses the method described in [Ber96]. It computes the eigenvalues using equations (4.83) and (4.84), assuming that the elements computed in (4.85) are zero. It also assumes that (4.84) gives zero for $k \neq 0$. The dependence of σ_r on s is ignored, and $\Delta\psi_r$ is assumed to be zero. The bunches are assumed to be symmetric, and thus all the I_r in equation (4.83) are taken to be the same. Also, the feedback contribution to the Z 's described in equation (4.98) is included, with approximations similar to those for the impedance.

The code only computes the modes near $\Omega = \omega_y$. It evaluates all impedances and form factors at $\Omega = \omega_y$. Future updates will include code for finding the fixed point by evaluating the impedances and form factors at the computed Ω .

4 Getting the vlasov Code

The vlasov package can be obtained by anonymous ftp to `ftp.slac.stanford.edu`, in the directory `users/alhy`. Get the file `vlasov.tar.gz`. The program is designed to be used in UNIX systems. To compile, the program

requires gcc version 2.7.2 or later, as well as libg++ version 2.7.1 or later. To view the plots, you need xmgr version 3.01, patch level 7.

References

- [Ber96] J. Scott Berg. *Coherent Modes for Multiple Non-Rigid Bunches in a Storage Ring*. PhD thesis, Stanford University, Stanford, CA, March 1996. SLAC report SLAC-R-478.
- [BR95a] J. Scott Berg and Ronald D. Ruth. Transverse instabilities for multiple nonrigid bunches in a storage ring. *Phys. Rev. E*, 52(3):R2179–2182, September 1995.
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- [Wie93] Helmut Wiedemann. *Particle Accelerator Physics*. Springer-Verlag, Berlin, 1993.

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