ABCI PROGRESSES AND PLANS: PARALLEL COMPUTING AND TRANSVERSE SHOBUDA-NAPOLY INTEGRAL

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Abstract

In this paper, we report the recent progresses of ABCI. First, ABCI now supports parallel processing in OpenMP for a shared memory system, such as a PC with multiple CPUs or a CPU with multiple cores. Tests with a Core2Duo (two cores) show that the new ABCI is about 1.7 times faster than the non-parallelized ABCI. The new ABCI also supports the dynamic memory allocation for nearly all arrays for field calculations so that the amount of memory needed for a run is determined dynamically during runtime. A user can use any number of mesh points as far as the total allocated memory is within a physical memory of his PC. As a new and important progress of the features, the transverse extension of Napoly integral (derived by Shobuda) has been implemented: it permits calculations of wake potentials in structures extending to the inside of the beam tube radius or having unequal tube radii at the two sides not only for longitudinal but also for transverse cases, while the integration path can be confined to a finite length by having the integration contour beginning and ending on the beam tubes. The future upgrade plans will be also discussed. The new ABCI is available as a Windows stand-alone executable module so that no installation of the program is necessary.

INTRODUCTION

ABCI is a computer program which solves the Maxwell equations directly in the time domain when a bunched beam goes through an axi-symmetric structure on or off axis. Since its first release of the version 6.2 in 1992 [1], ABCI has been widely used in accelerator community to compute wake fields generated by a bunched beam passing through an axi-symmetric structure on or off axis. At the second release of the version 8.8 [2], published in 1994, many new features were implemented such as the higher speed of execution (three-five times faster) and the improved capabilities of Fourier transformations. Since then, some new features have been added and improvements have been made. At the time of the second release of user's guide, most of users were used to run ABCI on IBM/VAX main-frame computers or UNIX workstations. Nowadays, many users have their own personal computers with Microsoft Windows Operation System, and prefer to run ABCI on Windows. In 2005, the author published the comprehensive package of the Windows version of ABCI, including the updated manual[3], the sample input files, the source codes and the Windows version of TopDrawer, TopDrawW. This version of ABCI is the Windows stand-alone executable module, and neither compilation of the source code nor installation of the program to a computer is necessary. Together with the TopDrawer for Windows, all works (computation of wake fields, generation of figures and so on) can be done simply and easily on Windows alone. The Windows package and all information can be downloaded from the ABCI home page:

http://abci.kek.jp/abci.htm

ABCI_MP AND NEW FEATURES

The author has been actively updating the ABCI program since the release of the Window package of ABCI. ABCI has been renamed to ABCI_MP since the release of the version 10 (when the parallel computing capability using OpenMP was implemented). The latest ABCI_MP is the version 12.2 and the following four significant and new features have been implemented:

1. support for parallel processing in OpenMP for shared-memory computers, namely a PC with several CPUs (e.g., 8 AMD Opterons) or a CPU with multiple cores (e.g., Intel Core2Duo), which share the same memory. It also supports multi-threaded shared-memory system. Tests with a Core2Duo PC (two cores) show that ABCI_MP is about 1.7 times faster than a non-parallelized ABCI.
2. adaptation of the dynamic memory allocation for nearly all arrays for field calculations so that the amount of memory needed for a run is determined dynamically during runtime. You can use any number of meshes as far as the total allocated memory is within a physical memory of your PC.
3. the transverse extension of Napoly integral (derived by Shobuda) so that ABCI can now handle calculations of transverse wake potentials in structures having unequal tube radii at the two sides, still keeping the integration path confined to a finite length by having the integration contour beginning and ending on the beam tubes [4]. More details are described in the coming section.
4. Improvement of the open boundary condition. ABCI used to adopt the conventional open boundary condition where all waves propagating in the beam pipe are assumed to have the phase velocity equal to the speed of light. But in general cases, the propagating fields can be represented as a linear superposition of the waveguide modes and each mode has its own phase velocity which varies in frequency. Aharonian et al. introduced a more advanced formula for the open boundary conditions in the DBCI code [5] and ABCI now

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adopts it. In this method, the phase velocities of all the travelling waveguide modes are represented correctly in the code.

OTHER MAIN FEAURES INHERITED FROM VERSION 9.4

The other main features of ABCI inherited from the version 8.8 or added at the release of the version 9.4 include:

1. The "moving mesh" option which drastically reduces the number of mesh points which have to be stored, and thus allows calculation of wake potentials in very long structures and/or for very short bunches. Not all of these mesh points are simultaneously necessary at each time step for the calculation of fields. If we are only interested in the wake potentials not too far behind the beam, the fields need to be calculated only in the area called, "window". The window is defined by the area of the structure which starts at the head of the bunch and ends at the last longitudinal coordinate in the bunch frame (which is often the tail of the bunch) up to which we want to know the wake potentials. The fields in front of the bunch are always zero. The fields behind the window can never catch up with the window, which is moving forward with the speed of light, and thus do not affect the fields inside the window. Since the calculation is confined to the area inside the window, the "mesh" is needed only for this frame and moves together with it.
2. The "Napoly integration" method [6] improves calculation of wake potentials in structures such as collimators, where parts of the boundary extend below the beam pipe radius. Their calculation can be carried out directly with beam pipes of short length at both ends. The conventional integration method at the radius of the beam pipe breaks down when a part of the structure comes down below it, or when the radii of the two beam pipes at both ends are unequal. One can avoid that the integration contour intersects the structure by moving it closer to the axis. However, then a very long outgoing beam pipe becomes necessary to allow the fields to catch up with the beam far behind the structure. Napoly's integration method is a solution to this classical problem. It eliminates the contribution from the outgoing beam pipe, and puts the integration contour back to the finite length over the gap of the structure. For the monopole (longitudinal) wake potential case, this method permits a structure with unequal beam radii at both ends. However, the original Napoly method could not deal with such a structure for the dipole wake potential calculations. The integration contour can be deformed to three straight lines ("Napoly-Zotter contour"[6]), which can be chosen by the user within certain limits.
3. Elaborate Fourier transformation techniques to compute impedances, frequency spectrum of the loss factors, and so on are implemented using the data windowing technique. The user can choose the window function from three standard functions: Blackman-Harris, Kaiser-Bessel, or Gaussian functions.
4. The possibility of mesh sizes different in the axial and radial directions, and the possibility of using "variable" radial mesh sizes (different for different radial intervals) help for a better fitting of the mesh to the structure and often permit to reduce the total number of mesh points.
5. In addition to the conventional method of inputting the shape of the structure by giving the absolute coordinates of points, users can input the structure by giving the increments of coordinates from the previous positions (incremental input). In this method, one can use repetition commands to repeat input blocks which saves time and labour when the same structure repeats many times.
6. The graphic presentation of the results of the computation are produced in the form of TopDrawer input file. By this method, ABCI's graphical output becomes independent of computers and graphic devices. One can easily import/export the graphical output to other computers, and/or edit it if desired.
7. Wake potentials for a counter-rotating beam of opposite charge can be calculated instead of usual ones for a beam trailing the driving beam.

SHOBUDA-NAPOLY INTEGRAL

The Napoly integral is the very useful method for calculations of wake potentials in structures where parts of the boundary extend below the beam pipe radius or the radii of the two beam pipes at both ends are unequal. It reduces CPU time a lot by deforming the integration path so that the integration contour is confined to the finite length over the gap of the structures. As stated before, the original Napoly method cannot be applied to the transverse wake potentials in a structure where the two beam tubes on both sides have unequal radii . In this case, the integration path needed to be a straight line and the integration is stretched out to an infinite, in principle. Shobuda extended the Napoly integration method to general cases [4], and now the Shobuda-Napoly method allows the integration contour to be confined to the finite length even for the transverse wake potential cases when the two beam tubes have unequal radii. ABCI automatically finds the best deformed contour for this integral. There are the three parameters that specify the deformed integration contour: z_1, z_2 and a_0 (see Fig.1). The longitudinal wake potential for the dipole mode is given by the formula:

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$$
\begin{aligned}
W_z^{(1)}(r,\theta,s) = -\frac{r}{2}\cos\theta \\
\times\Bigg\{ \frac{\lambda(s)}{\pi\varepsilon_0} r_0 \left(\frac{1}{a_{out}^2} - \frac{1}{a_{in}^2} \right) \\
+ \frac{1}{a_{\min}} \int_{z_1}^{z_2} \left[E_z \left(\frac{a_{\min}}{a_0} + \frac{a_0}{a_{\min}} \right) - Z_0 H_z \left(\frac{a_{\min}}{a_0} - \frac{a_0}{a_{\min}} \right) \right] dz \\
+ \frac{1}{a_{in}} \int_{a_{in}}^{a_0} \left[\frac{a_{in}}{r'} + \frac{r'}{a_{in}} \right] (E_r + Z_0 H_\theta) dr' \Big|_{z=z_1} \\
+ \frac{1}{a_{in}} \int_{a_{in}}^{a_0} \left[\frac{a_{in}}{r'} - \frac{r'}{a_{in}} \right] (E_\theta - Z_0 H_r) dr' \Big|_{z=z_1} \\
+ \left(\frac{1}{a_{out}^2} - \frac{1}{a_{in}^2} \right) \int_0^{a_0} r' (E_r + Z_0 H_\theta - E_\theta + Z_0 H_r) dr' \Big|_{z=z_{crit}} \\
+ \frac{1}{a_{out}} \int_{a_0}^{a_{out}} \left[\frac{a_{out}}{r'} + \frac{r'}{a_{out}} \right] (E_r + Z_0 H_\theta) dr' \Big|_{z=z_2} \\
+ \frac{1}{a_{out}} \int_{a_0}^{a_{out}} \left[\frac{a_{out}}{r'} - \frac{r'}{a_{out}} \right] (E_\theta - Z_0 H_r) dr' \Big|_{z=z_2} \Bigg\} \quad ,
\end{aligned}
$$

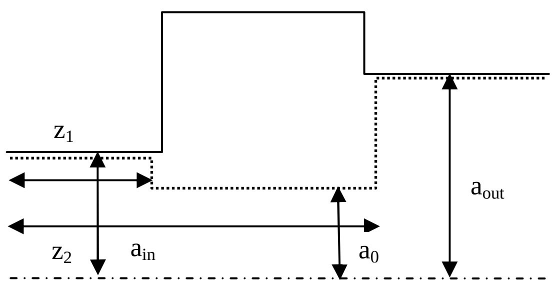

Figure 1: The contour for the Shobuda-Napoly integration method for a structure with unequal beam pipe radii.

where $\lambda(s)$ is the longitudinal line charge density, r_0 is the radius of the ring-shaped driving beam, a_{in} and a_{out} are the radii of the incoming and outgoing beam pipes, respectively, and Z_0 and ε_0 are the impedance and the permittivity of the vacuum, respectively. The fields E and H are ABCI calculation results. The parameter a_{min} is the minimum of a_{in} and a_{out} and the z coordinate z_{crit} is z_1 if a_{in} is larger than a_{out} and it is z_2 if a_{out} is larger than a_{in}. The transverse wake potential $W_t^{(1)}$ can be calculated from $W_z^{(1)}$ using the Panovsky-Wenzel theorem as

$$W_t^{(1)}(r,\theta,s) = \int_0^s \frac{\partial}{\partial r} W_z^{(1)}(r,\theta,s) ds \, .$$

The previous version of ABCI, actually, could, compute the transverse wake potential of the dipole fields using the conventional integration method on a straight line even for a structure with unequal beam pipes radii and correct the difference of the potential energies in the two beam pipes at both ends. The problem of this method is naturally that very long beam pipes, in particular on the outgoing side, may be necessary to simulate the interation between a beam and the wake fields accurately. To see how quickly the calculation result converges as a function of the outgoing beam pipe length in the conventional method, we compare the transverse loss (kick) factor of the Shobuda-Napoly integration method and the conventional integration method for a step-out structure shown in Fig.2. The broken straight line in this figure shows the integration path for the conventional integration method. The bunch length is 2cm. Figure 3 shows the comparison result. The horizontal axis shows the length of the outgoing beam pipe. We can see that about 20 times longer beam pipe than the aperture of the pipe is necessary to calculate the transverse wake potential accurately.

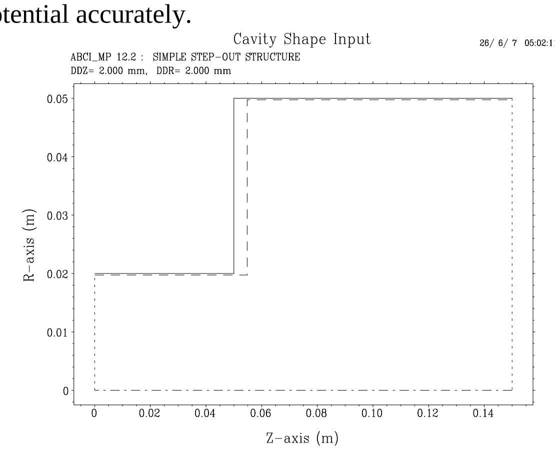

Figure 2: The step-out structure for comparison.

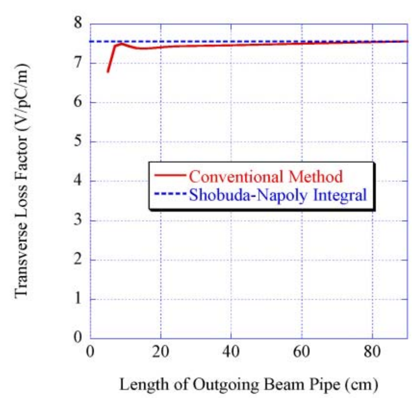

Figure 3: Comparison between the Shobuda-Napoly and the conventional integration methods.

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