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New Features and Applications of ABCI

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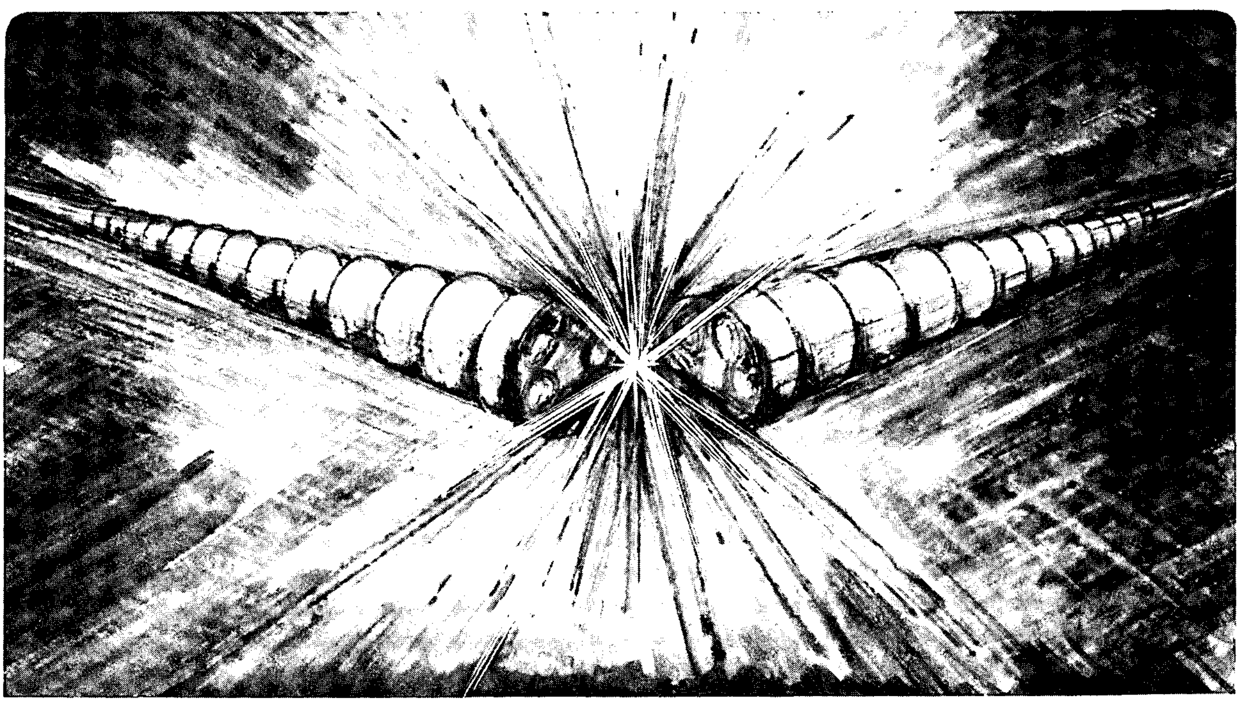

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New Features and Applications of ABCI*

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NEW FEATURES AND APPLICATIONS OF ABCI

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ABSTRACT

ABCI is a computer program which solves the Maxwell equations directly in the time domain when a Gaussian beam goes through an axi-symmetrical structure on or off axis. Many new features have been implemented in the new version of ABCI (presently version 6.2.4), including the "moving mesh" and Napoly's method of calculation of wake potentials. The mesh is now generated only for the part of the structure inside a window, and moves together with the window frame. This moving mesh option reduces the number of mesh points considerably, and very fine meshes can be used. Napoly's integration method makes it possible to compute wake potentials in a structure such as a collimator, where parts of the cavity material are at smaller radii than that of the beam pipes, in such a way that the contribution from the beam pipes vanishes. For the monopole wake potential, ABCI can be applied even to structures with unequal beam pipe radii. Furthermore, the radial mesh size can be varied over the structure, permitting to use a fine mesh only where actually needed. With these improvements, the program allows computation of wake fields for structures far too complicated for older codes. Its usefulness is illustrated by showing some numerical examples. A newly installed mesh generator performs automatic circular and elliptical connections of input points. In addition to the conventional method, ABCI permits the input of the structure geometry by giving the increments of coordinates from the previous positions. In this method, one can use the repetition commands to repeat input blocks when the same structure repeats many times. Plots of a cavity shape and wake potentials can be obtained in the form of a Top Drawer file.

INTRODUCTION

The first version (version 2.0) of ABCI (Azimuthal Beam Cavity Interaction)[1] was written in 1984, however, its manual was published only in 1988. It was a computer program which solved the Maxwell equations directly in the time domain when a Gaussian beam passed through an axi-symmetrical structure on or off axis. It used the FIT method[2] to discretize the Maxwell equations, similar to TBCI.[3] However, in addition to some internal differences, it was preferable to TBCI mainly due to capability to change dimensions of arrays to make a larger mesh if necessary (which could not be done in TBCI which was only distributed in the compiled form), and the possibility of different mesh sizes in r- and z-directions. Furthermore, one could input the mesh sizes rather than the number of mesh lines, and could use `CONTINUE` cards to calculate with different bunch lengths and/or mode numbers (m=0 or 1) in a single job. In this program, the beam was assumed to be hollow, with surface charges azimuthally distributed either in an uniform or sinusoidal way. In the first version of ABCI, the radius of the hollow beam was always chosen to be equal to that of a beam pipe so that no fields were brought with it into the structure of concern. The wake fields were integrated at the radius of the beam pipe, which left the integration across the cavity gap as the only contribution to the wake potentials and thus made long beam pipes unnecessary . The program was compact, and simply structured so that users could easily change important parameters such as an array size for the number of mesh points, and modify the program for their special needs. Since the main body of the program was small, relatively large arrays could be allocated to mesh points in a limited memory space. Furthermore, permitting unequal mesh sizes in the axial and radial directions helped to reduce the number of mesh points.

However, if one tried to apply the program to long structures and/or very short bunches, the total number of mesh points easily becomes of the order of many hundred thousands or more. For example, the recently proposed "stagger-tuned" structure for the NLC of SLAC[4] consists of a disc-loaded waveguide with a large number cells with slightly different dimensions of the order of μm or less. In order to correctly represent such tiny differences, many million mesh points would be needed.

A. Moving Mesh

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. One of main new features of ABCI is the implementation of this "moving mesh" in lieu of the conventional static mesh. Since the window is usually much smaller than the total structure, the number of mesh points can be drastically reduced. In addition, since the window length is determined only by the last longitudinal coordinate of the wake potentials, the number of mesh points does not change as the structure length increases.

B. Napoly's Integration Method

Another main new feature of ABCI is the implementation of "Napoly's integration method" of fields to calculate wake potentials.[5,6] 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. The only alternative was to integrate over a straight line at an allowable radius and with beam pipes long enough 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 (the integration along the structure surface was already described by Gluckstern and Neri[7] in 1985). It relies on the expression of the wake potentials, at any multiple order, as an integral of electromagnetic fields along any one dimensional conture spanning the structure longitudinally. For the particular case of the contures parallel to the r- and z-axes, the integration is considerably simplified.[6] For this reason, ABCI has an option which uses a path of integration ("Napoly-Zotter conture") that starts as usual along the beam pipe, then descends radially to pass underneath the smallest material structure radius. It then rises again to the radius of the outgoing beam pipe and moves along it to the end of the structure (Napoly's method and a proper integration conture are actually automatically chosen as soon as a material point has a radius smaller than the beam pipe). This path is shown in Fig. 1 by the broken curve.

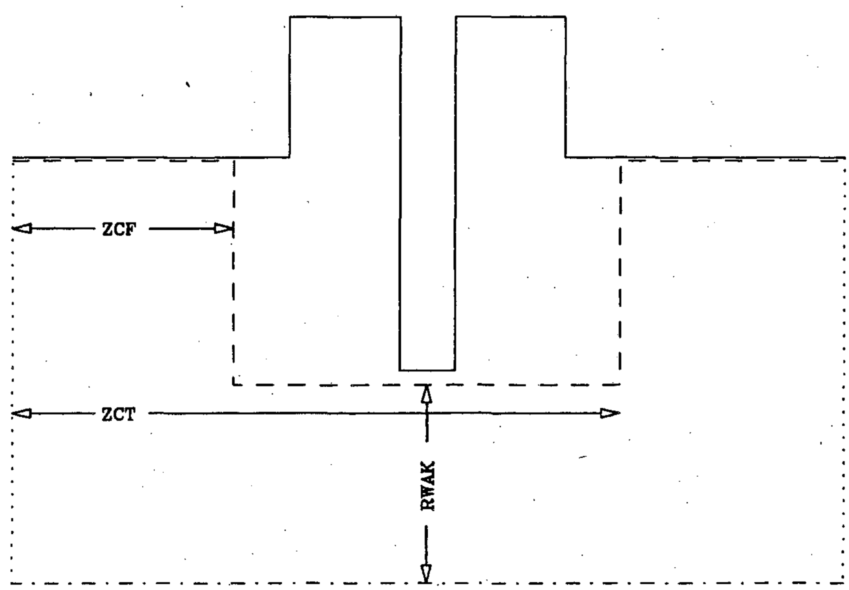

Fig. 1. Napoly-Zotter integration conture for computation of wake potentials.

The first axial coordinate where the path descends, the radius to which it goes, and the second axial coordinate where it rises again can also be chosen as input commands. In particular for structures with a complicated boundary extending to the inside of the beam pipes, this technique leads to a considerable saving in computing time. For the monopole (longitudinal) wake potential case, this method permits a structure with unequal beam radii at both ends. For the dipole (transverse and longitudinal) wake potential case, the beam pipe radii must be equal.

C. Other New Features

In addition to these two new main features mentioned above, ABCI has a completely new mesh generator, which permits circular and elliptical inputs just as TBCI. The program allows variable radial mesh sizes for different radial intervals for the better fitting of mesh and reducing the total number of mesh points by permitting to use a fine mesh only where actually needed.. In addition to the conventional method of inputting the shape of the structure by giving the absolute coordinates of points, users can now 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 labor when the same structure repeats many times. The new ABCI also has better plotting facilities. It can show on a separate page each the input and actual shape of a cavity used for calculation, the wake potentials, and finally the Fourier transforms of the wake potentials. ABCI creates a "Top Drawer" file[8] for the corresponding figures. 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.

APPLICATIONS

I this section, we show a number of examples of structures which have so far been evaluated using the new version of ABCI.

A. Collimator

A Saclay collimator shown in Fig. 2 is a simple constriction of a beam pipe, which can be computed easily with the new version of ABCI using Napoly's method. The beam pipes at both sides have 5 cm length, long enough to allow wake fields to propagate in both z-directions like plane waves (this is the essential assumption for the engaged "open" boundary condition). The integration conture used is shown by the broken curve. The rms bunch length is chosen to be 0.5mm. The longitudinal loss factor was then found to be -1.755 $\times 10^{13}$ V/C. For comparison, longitudinal loss factors were also computed by the integration along a straight line at the inner radius of the collimator and subtracting the contribution of the beam pipe from it (similar to the "WAKCOR" option in TBCI). The results are shown by the solid curve in Fig. 3 as a function of the beam pipe length L at both sides. The dotted line denotes the loss factor obtained by Napoly's method. One can see that a quite long beam pipe ($\gtrsim$30cm) compared to the beam pipe radius of 1 cm is needed for the WAKCOR method to saturate to the correct result.

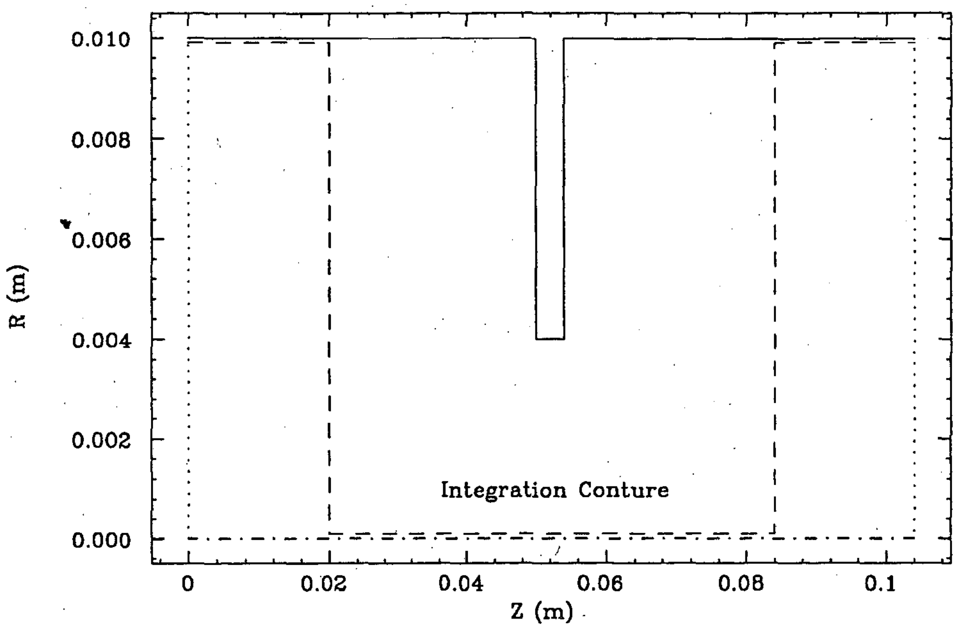

Fig. 2. Saclay collimator.

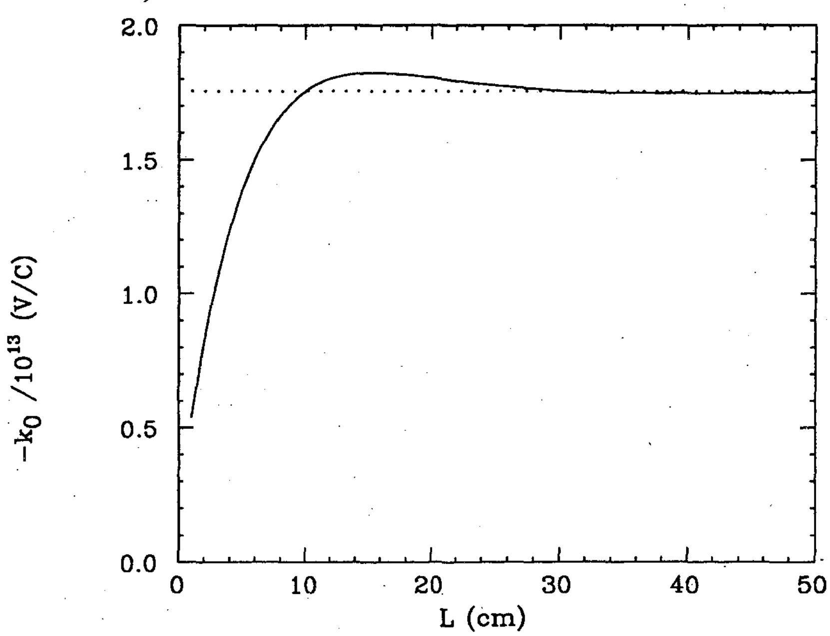

Fig. 3. Comparison of the longitudinal loss factor obtained by Napoly's method (dotted line) with that obtained by the "WAKCOR" method (solid line) as a function of beam pipe length L at both sides.

B. Step-in and Step-out Structures

Next, we show computations of loss factors of a tube with a step to a smaller radius (step-in) and to a larger one (step-out). Figure 4 shows the step-in structure used in this example. The integration path is denoted by the broken curve. The step-out structure for comparison is a mirror symmetrical image of the step-in structure. The bunch length is chosen to be 1cm. Figure 5 shows the (normalized) longitudinal wake potentials for the step-in structure. The broken and solid curves express the wake potentials with and without the potential energy difference term [5,6], respectively. The positive value of the broken curve predicts that the bunch will be accelerated after passing though the step-in structure. The resulting longitudinal loss factors for the step-in and step-out structures without the potential energy difference terms are -3.804 $\times 10^{11}$ V/C and -3.806 $\times 10^{11}$ V/C, respectively. They are equivalent within the limit of the computer accuracy. This result supports the analytical prediction.[9] The sum of those loss factors are compared with the one for a double-step geometry (pill box) shown in Fig. 6 obtained by integrating along a straight line at constant radius of the beam pipes. The result is summarized in Fig. 7. The horizontal axis L is the distance between the two steps in the pill box. The dotted line denotes the sum of loss factors for the two steps previously obtained, while the solid curve shows the loss factor for the pill box. One can see that the loss factor of the pill box converges to the sum for the two steps if they are sufficiently separated, and thus their interference becomes negligible. It is thus possible to split computation of long geometries in smaller parts and thus save memory and cpu time.

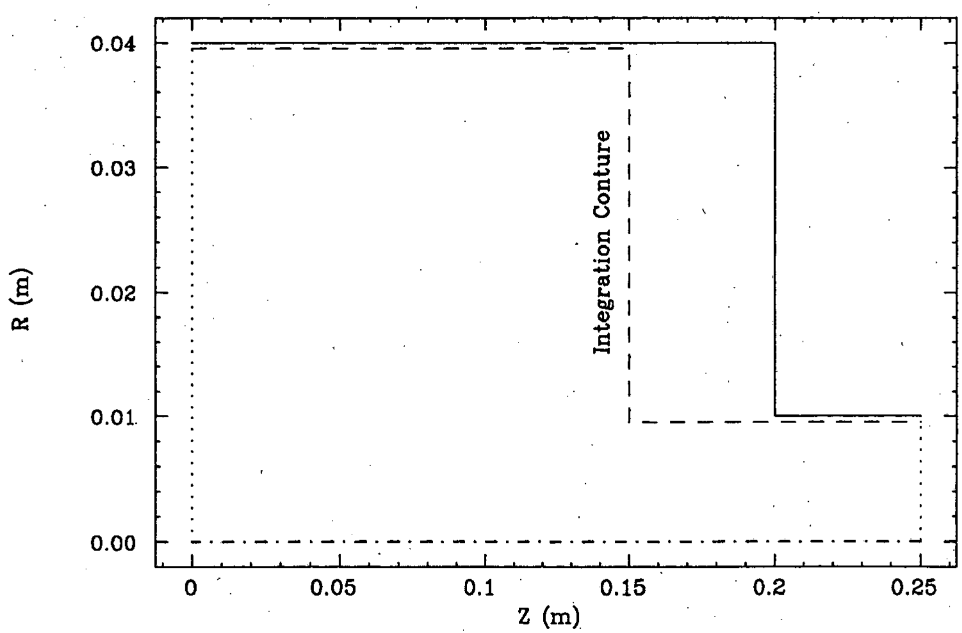

Fig. 4. Step-in structure.

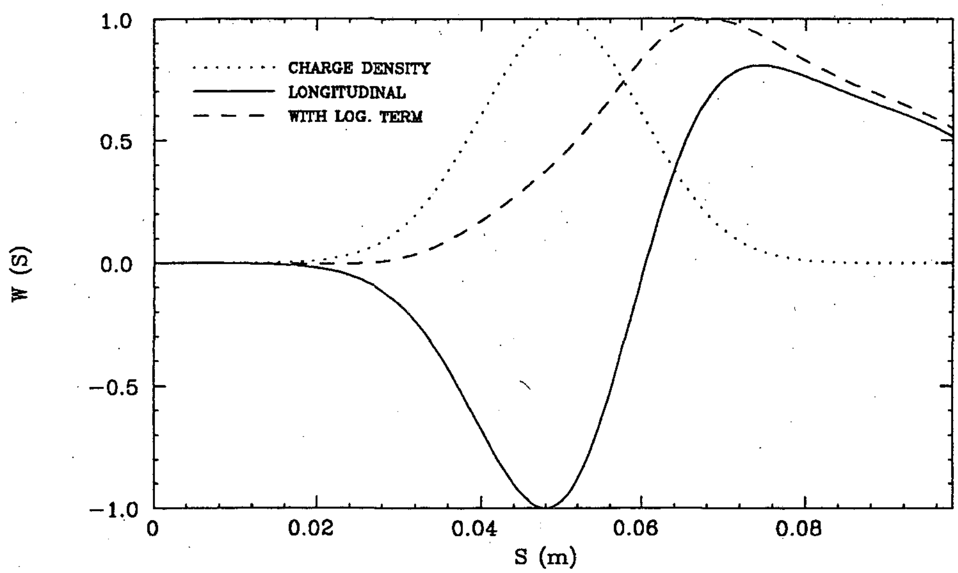

Fig. 5. Normalized longitudinal wake potentials for the step-in structure.

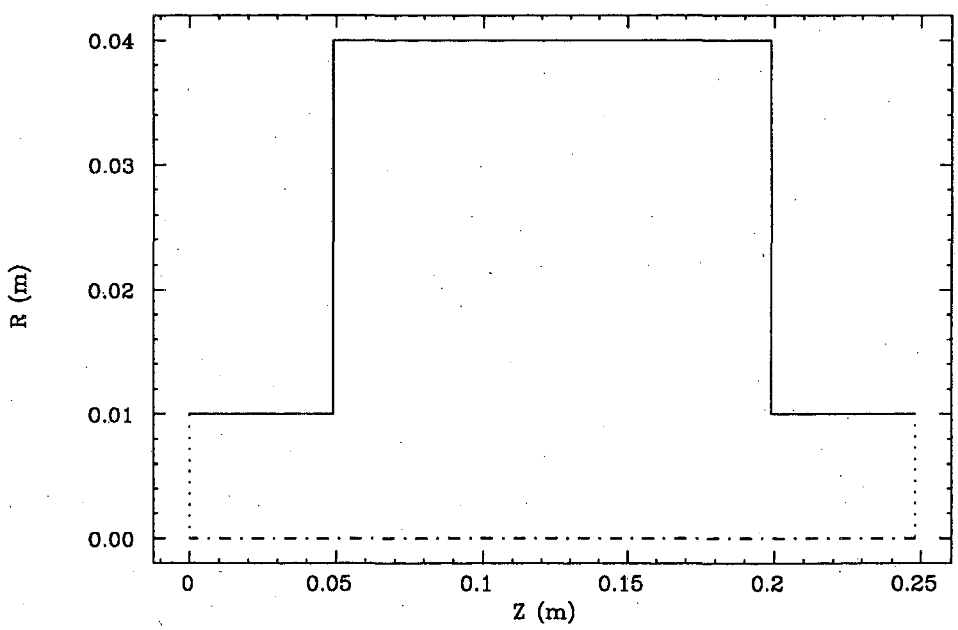

Fig. 6. Pill box structure.

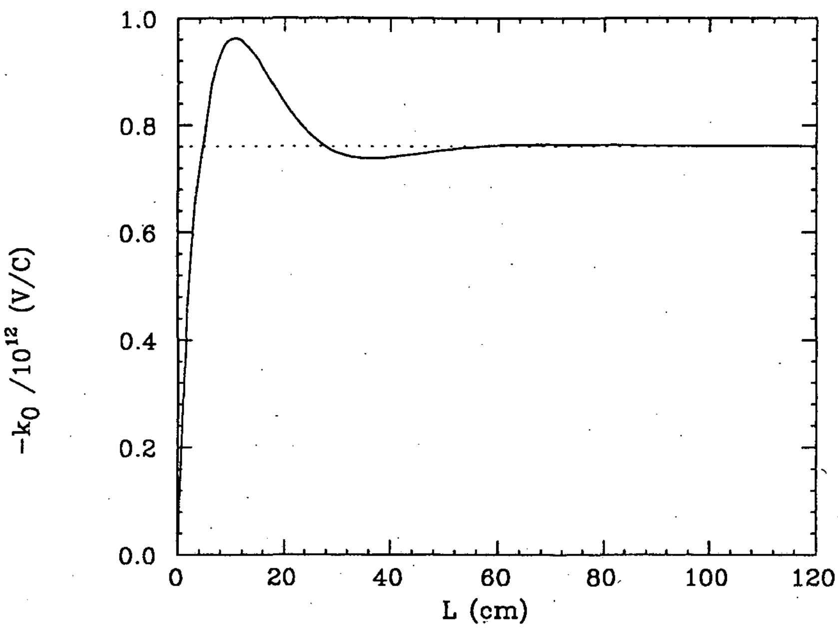

Fig. 7. Comparison of the sum of the longitudinal loss factors for the step-in and step-out structures (dotted line) with that for the pill box (solid line) as a function of the distance L between the two steps in the pill box.

C. CLIC stagger-tuned disk-loaded waveguide

A "stagger-tuned" structure of the CLIC (CERN Linear Collider) [10] is a disc-loaded waveguide composed of many cells with slightly different dimensions in such a way that the mode frequencies of each cell are distributed around the average values. Then, wake fields from each cell are expected to cancel each other so that the total wake fields will damp away rather quickly. Figure 8 shows an example of the CLIC stagger-tuned structure with 20 cells. The computed (normalized) transverse wake potential is plotted in Fig. 9 up to 1cm behind the head of the bunch (the bunch length in this case is only 0.17 mm). A clear damping of the transverse wake potential can be seen.

If TBCI is used instead in this example, it would have required about 4.6 million mesh points of uniform mesh size for required mesh sizes of 10 μm and for almost 7.2cm long structure of over 6.4mm radius. That would probably not fit any computer. With the moving, variable and unequal meshes, ABCI requires only 84 thousands mesh points, by factor $\sim$ 60 less than TBCI does. This example vividly illustrates that the new ABCI can open up a new possibility for computation of wake fields for structures which have been thought be too complicated to be dealt with.

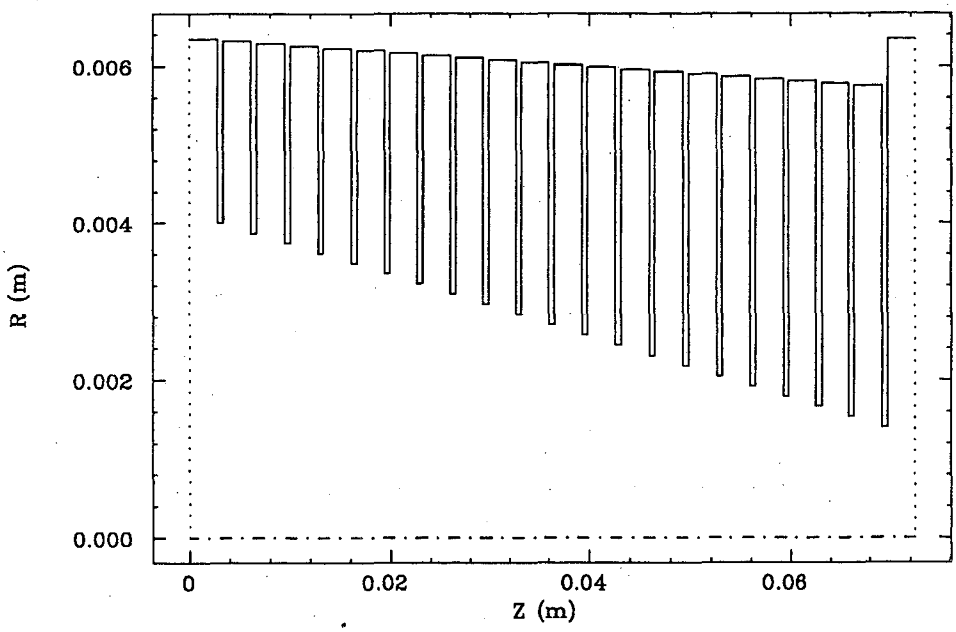

Fig. 8. Stagger-tuned disk-loaded waveguide of CLIC.

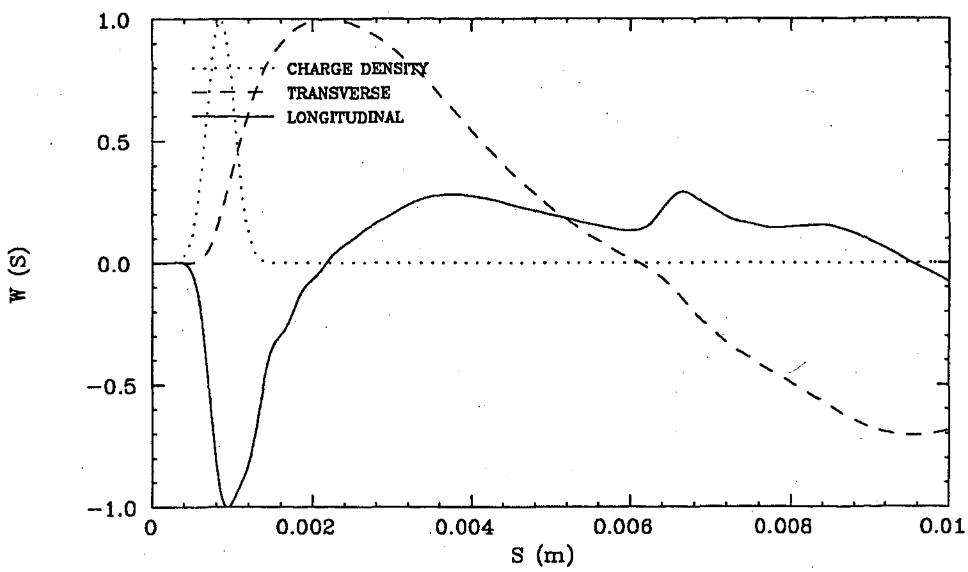

Fig. 9. Normalized transverse wake potential for CLIC stagger-tuned structure up to 1cm behind the head of bunch. The rms bunch length is 0.17mm.

CONCLUSIONS

The implementation of the moving mesh and Napoly's method for computing wake potentials, together with the option of variable radial mesh sizes, permits a large saving in memory and computing time, and thus drastically enhances the computational power of ABCI. It is now possible to compute wake potentials in much more complicated structures than before. The numerical examples shown in this paper demonstrate the usefulness and the remarkable advances in the new version of ABCI.

ACKNOWLEDGEMENTS

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REFERENCES

1. Y. H. Chin, CERN LEP-TH/88-3, 1988.
2. K. S. Yee, IEEE Trans. Antennas Propagat., Vol. AP-14, 302 (1966).
3. T. Weiland, DESY 82-015, 1982.
4. K. L. F. Bane, and R. L. Gluckstern, SLAC-PUB-5783, 1992.
5. O. Napoly, Part. Accelerators, 36, 15 (1991).
6. O. Napoly, Y. H. Chin and B. Zotter, DAPNIA/SEA/93-01, 1993.
7. R. L. Gluckstern, and F. Neri, IEEE NS-32, 5, 2403 (1985).
8. Top Drawer Manual, SLAC Computation Group, CTGM-189, 1980.
9. S. Heifets, SLAC/AP-81, ABC-14, 1990.
10. B. Zotter, private communications.

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