Time Domain Computation of Wakefields in Periodic Structures Using the Code ABCI.

Antonio Millich
CERN-SL
CH - 1211 Geneva 23

Abstract

The code ABCI (Azimuthal Beam Cavity Interaction) was created for the time domain computation of wakefields in accelerating structures of cylindrical symmetry. It allows the user to create a mesh which is contained in a window moving along with the exciting bunch rather than filling the whole structure. The number of mesh points required is therefore strongly reduced and so is the computation time. We have used ABCI to check and improve results previously obtained for the CLIC disk loaded structure at 30 GHz and to investigate the wakefields in the LEP type superconducting cavity at 352 MHz, which we plan to use in the drive linac. Results are also reported for the LIL (LEP Injector Linac) accelerating structure at 3 GHz, which is being used for tests in the CTF (CLIC Test Facility).

1. INTRODUCTION

In the two-beam acceleration scheme of CLIC the drive beam provides the 30 GHz power for the acceleration of the main beam by losing part of its energy to the transfer structure [1]. Prior to this transfer of energy the drive beam is accelerated by superconducting RF cavities of the LEP type (LEP-SC) at 352 MHz. The drive beam is formed by successive trains of densely populated bunches with standard deviation σ_z = 1 mm and spaced by one 30 GHz period which is 10 mm or 33 psec in time. The interaction of the beam with the LEP-SC structure generates longitudinal and transverse wakefields which affect the stability of the exciting bunch as well as that of the following ones. The computation of the wakefields excited by so short a bunch in a LEP-SC cavity with four cells (total length 2 m) has met in the past with the difficulty of requiring a very large number of mesh points and consequently of very long computation times. We have overcome this difficulty thanks to the recently available code ABCI[2], which computes the wakefields induced in axesymmetric structures by a bunch of particles by solving Maxwell's equations in time domain. ABCI presents among others the feature of allowing for different mesh sizes in the radial and longitudinal directions and of limiting the definition of the mesh to a window which moves along the structure with the bunch. The number of mesh points required for the wakefield computations is therefore strongly reduced and so is the iteration time.

2. WAKEFIELDS AND LOSS FACTORS OF THE LEP-SC STRUCTURE.

2.1 *Short range wakes.*

In our simulation of the LEP-SC cavities we have retained only the main part of the structure neglecting the end tapers as it is not sure that the present assembly will eventually be retained for the drive linac. The four cells geometry used in ABCI is shown in Fig. 1. The main cell parameters are:

a = 120 mm, iris aperture
b = 380 mm, cell radius
p = 420 mm, cell length.

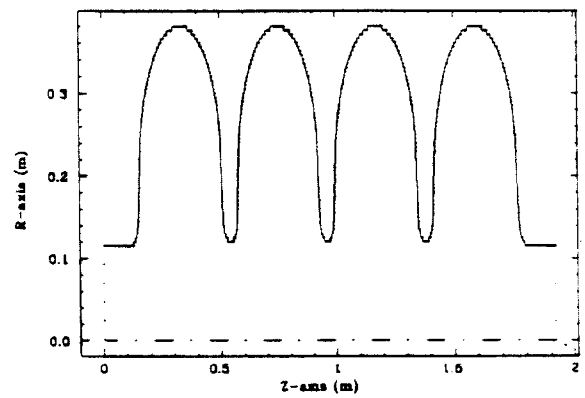

Figure 1. LEP-SC cavity shape used by ABCI

The short range wake of a bunch with σ_z = 1 mm and charge normalised to 1 pC was computed using a mesh step in the longitudinal direction of .2 mm and a window length of 10 mm which required 4200 mesh points. Fig. 2 shows the resulting longitudinal wakefield which appears negative because it is decelerating, together with the gaussian bunch shape. The longitudinal loss factor is K_l = 3.124 V/pC.

The transverse and the azimuthal wakefields are shown in Fig. 3 together with the longitudinal wake associated with transverse modes. The transverse kick factor is K_t = 0.586 V/pC/m. The total computation time for these results was 190 sec on the IBM 3090 mainframe.

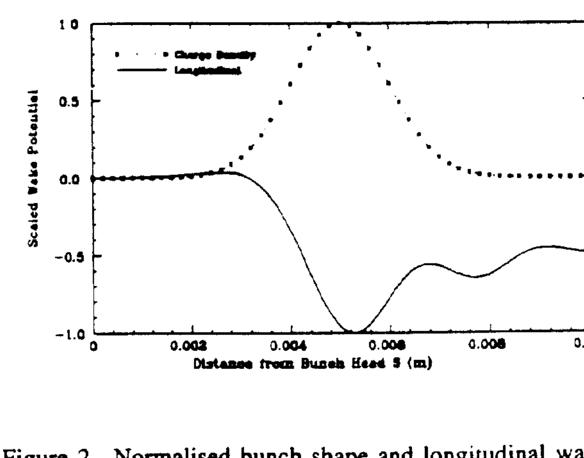

Figure 2. Normalised bunch shape and longitudinal wakefield of the LEP-SC cavity

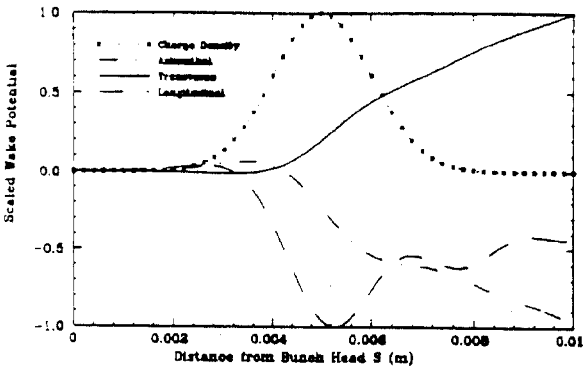

Figure 3. Normalised bunch shape, transverse and azimuthal wakefields of the LEP-SC cavity

2.2 Loss factors dependence on bunch length.

We have investigated the dependance of the loss factors with bunch length and found an approximation law by means of Mathematica. Table 1 gives the values of the longitudinal loss factor and of the transverse kick factor as function of bunch length for σ_z varying from 30 mm down to 1 mm.

Table 1

σ_z (mm)	K_l (V/pC)	K_t (V/pC/m)
1	3.124	0.586
2	2.223	0.793
5	1.389	1.226
8	1.096	1.472
10	0.984	1.578
15	0.803	1.776
20	0.682	1.827
25	0.626	1.838
30	0.568	1.976

Fig 4 shows the graphs of the fitting polynomial for the transverse kick factor which is:

$K_t = 0.677\,\sigma_z^{0.5} - 0.060\,\sigma_z$ σ_z in mm, K_t in V/pC/m

The approximation law for K_t can be used to determine the transverse kick factors for σ_z smaller than 1 mm. [3]

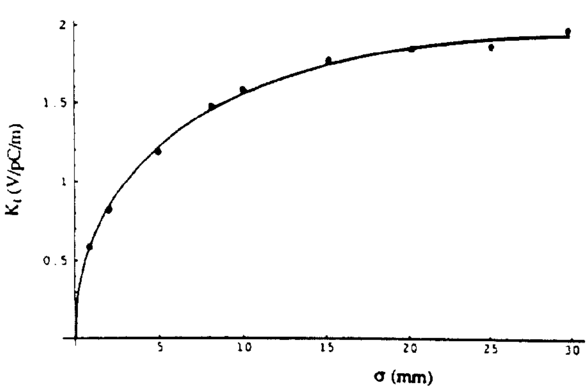

Figure 4. Transverse loss factor as function of bunch sigma for the LEP-SC cavity

2.3 Long range wakes.

While the short range wakes and the associated loss factors describe the influence of the exciting bunch upon itself, the long range wakefields determine the actions one bunch has on the following ones in a train. Of particular concern for the drive beam is the transverse kick given by the leading bunches to the trailing ones when transverse modes are excited in the accelerating structures. We have extended the computation of the transverse wakes for a bunch of σ_z = 1 mm to cover the length of 430 mm or 43 bunches and we have stored it in a file for use in tracking programs. An interesting feature of ABCI allows for the computation of the longitudinal and transverse impedances by Fourier transformation of the respective time domain wakefields. Of course the computation is an approximation since the exact value requires an infinitely long wake. Fig. 5 shows the spectrum of the real part of the transverse impedance of the LEP-SC structure computed from a 12 m long wake. The transverse impedance, obtained by integration of the spectrum over frequency, is shown in Fig. 6. The contribution of the individual modes appear as steps in the integrated function. In these computations we have used a 30 mm long bunch in order to minimise the computation time and also to limit the spectrum to the main low frequency modes.

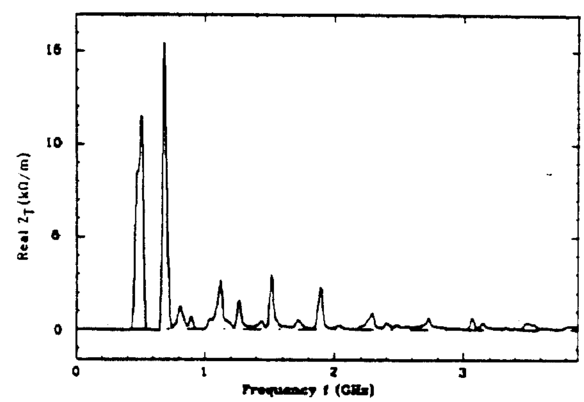

Figure 5. Real part of the LEP-SC cavity impedance.

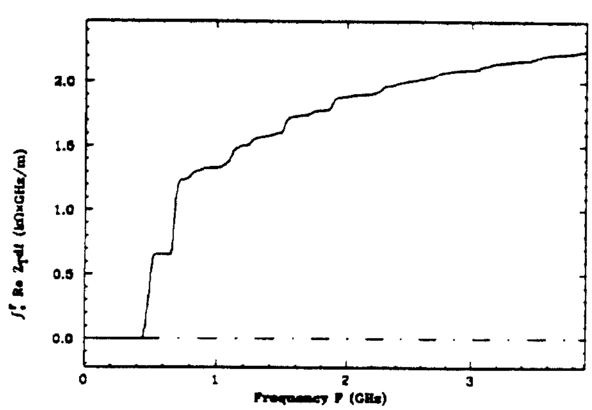

Figure 6. Integrated transverse impedance of the LEP-SC cavity

2.4 Higher order harmonics.

For the purpose of extending the useful portion of the 352 MHz accelerating wave, it has been proposed[4] to add a second and possibly a fourth harmonic superconducting structures at 704 and 1408 MHz respectively in the drive linac. We have investigated the effect of these structures on the drive beam by computing the wakefields and loss factors for a gaussian bunch with standard deviation 1 mm. We have scaled the LEP-SC cavity dimensions down a factor two and four respectively and found the longitudinal loss factors and transverse kick factors of the second and fourth harmonic cavities. The results are summarised in Table 2. We see that the normalised loss and kick factors per unit structure length scale approximately as the square and third power of the frequency ratio.

Table 2

	1st harmonic	2nd harmonic	4th harmonic
K_l (V/pC)	3.124	4.122	5.883
K'_l (V/pC/m)	1.627	4.249	12.256
K_t (V/pC/m)	0.586	3.207	17.953
K'_t (V/pC/m^2)	0.305	3.341	37.392

3. WAKEFIELDS OF THE MAIN LINAC 30 GHZ STRUCTURE.

The results of computations done with the code TBCI and using the frequency analysis method have been reported in a previous paper[5]. For the purpose of comparison we have input the CLIC main linac structure geometry in ABCI and computed the short term longitudinal and transverse wakes as well as the loss and kick factors. The wakes are very similar in amplitude and shape to those found in previous computations and the numerical values of the loss and kick factors $K_l = 25.52$ V/pC and $K_t = 3.36\ 10^3$ V/pC/m for the three cells section studied are within a few percent of the values found with the two previously used methods. We therefore conclude that the values supplied by ABCI are valid within the limits of the accuracy of the mesh.

4. COMPUTATIONS FOR THE LIL 3 GHZ STRUCTURE.

A section of the LIL structure is presently used in the CLIC Test Facility to accelerate the test beam. In order to investigate the beam dynamics when traversing the structure, we have computed the wakefields using ABCI. The LIL cavity geometry is shown in Fig. 7. The main parameters of the average cell are[6]:

a = 11 mm iris radius,
b = 41.5 mm cell radius
p = 33 mm cell length

We have computed the short range wakes of a bunch with $\sigma_z = 1$ mm and found the longitudinal loss factor to be $K_l = 6.95$ V/pC while the transverse kick factor is $K_t = 1.42\ 10^2$ V/pC/m for the three cells. We have used a longer bunch ($\sigma_z = 5$ mm) to compute the long range wake and the transverse impedance of the structure. Fig. 8 shows the real part of the transverse impedance with the main contributing modes up to 25 GHz. This information is used to determine transverse kicks affecting the bunches in a train.

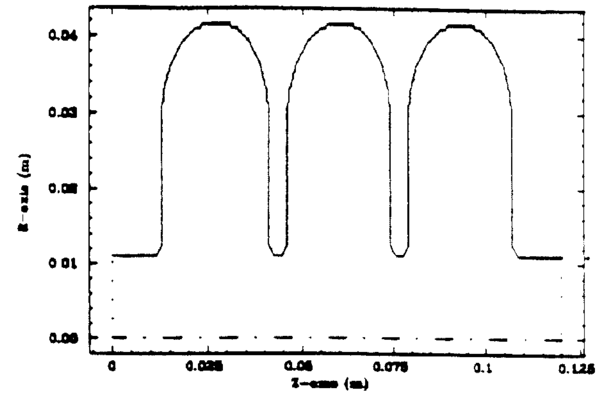

Figure 7. LIL cavity shape (average cell) as used by ABCI

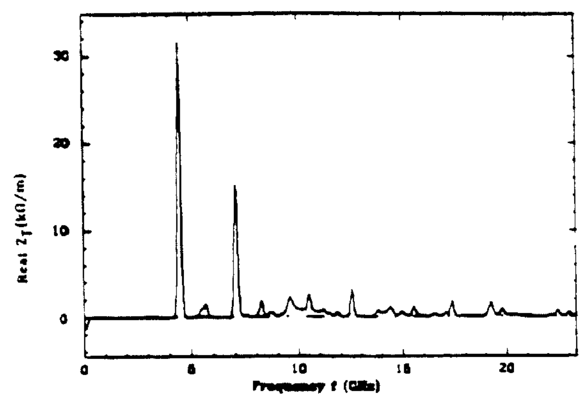

Figure 8. Real part of LIL cavity transverse impedance

5. CONCLUSION AND ACKNOWLEDGEMENT.

In our investigation we have found extensive and reliable results on accelerating structures with different geometry and ranging in frequency from 352 MHz to 30 GHz. These results are presently being used to simulate the beam dynamics in tracking programs. Because of its free availability, its simplicity of utilisation and its efficiency, the code ABCI is the ideal tool to determine the wakefields, impedances and now also the loss factors spectra of axesymmetric accelerating structures. It is a pleasure to acknowledge the kind assistance of its author Yong Ho Chin in adapting the code to suit our computing environment and specific needs.

6. REFERENCES

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6. S. Lütgert, Private Communication.