2D CODES SET FOR RF CAVITIES DESIGN

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ABSTRACT

For computer added design was developed set of codes to calculate in 2D approximation electromagnetic, electrostatic, magnetostatic fields, stationary distribution of temperature, thermal elastic stresses in hardware elements with either rotational or translational symmetry and arbitrary cross shape. In code for electromagnetic field calculation the possibility to calculate modes of any type in cavities and all modes in infinitely repeating structures is realized. Every hardware element may be filled by several materials, differing in their characteristics. Nonlinear properties of material are taken into account to calculate temperature or magnetic field distribution. All codes are developed at the general base. Usage of this codes allows both unify procedure of different calculations and investigate relations between different processes, like cavity heating due to RF power dissipation and influence of thermal stresses (due to heating) on RF cavity characteristics. For last purpose system for automatic data exchange between codes is developed. Some examples of applications are presented.

INTRODUCTION

In the development of the particle accelerators systems it is needed, by using numerical modeling, to solve problems, which are different in physical sense but are similar in mathematical approach. Now there are known wary many codes for calculation partial problems. When were developed with using differing methods, these codes, as a rule, don't create united system and user must spend additional efforts to learn run with different codes. In this paper is represented set of 2D codes for calculation field distributions. All codes are developed at the general base with using one mathematical approach.

DESCRIPTION OF THE PROBLEMS

For all problems, described below, we assume the total region, in which calculation will be done, to be divided into subregions. Subregions are filled with materials, differing in physical characteristics. If total region has symmetry plane, solution may be obtained for one half with using appropriate boundary conditions at the symmetry plane. The boundaries of subregions and regions consist of line and circular segments All problems are solved both in cartesian and cylindrical systems, allow to calculate hardware elements both with rotational and translational symmetry.

To determine the temperature or electrostatic potential distribution one finds the distribution of the variable U satisfying the following conditions:

$$\mathrm{div}(\ \alpha\ \mathrm{grad}\ U\ ))\ = q \qquad (1)$$

$$U\Big|_{\gamma_1} = U0 \qquad (2)$$

$$\alpha(n\ \mathrm{grad}\ U)\Big|_{\gamma_2} = P \qquad (3)$$

$$\alpha(n\ \mathrm{grad}\ U)+\beta\ (U-U0)\Big|_{\gamma_3} = 0 \qquad (4)$$

n is the unit normal to the boundary.

Physical sense of the problem defines sense of the coefficients in (1)-(4). For heat problem $\alpha(x1,x2,U)$ is the thermal conductivity, $q(x1,x2,U)$ and $P(x1,x2,U)$ are the densities of the volume and surface heat sources respectively. For electrostatic problem is the permittivity of the material and it is constant inside subregion. Condition of the heat transfer (4) is essential only for heat problem, where β is heat transfer factor at the boundary part which has the temperature T0. Assuming electrostatic problem under solution, electric field distribution we find from usual definition

$$E = -\mathrm{grad}\ U \qquad (5)$$

To determine the magnetic field distribution one finds the distribution of the vector potential A which in isotropic media satisfies the equation

$$\mathrm{rot}(\ \frac{1}{\mu}\ \mathrm{rot}\ A\ ))\ = \mu_0 j \qquad (6)$$

and the following boundary condition at infinity

$$A\Big|_{\infty} = 0 \qquad (7)$$

The distribution of the magnetic induction vector B is determined from relation

$$B = \mathrm{rot}\ (\ A\ ) \qquad (8)$$

The thermoelasticity problem is solved with respect to displacement in usual formulation [1]. The solution of the problem is determined by the equilibrium equation

$$\mathrm{div}\ \sigma_i + g_i = 0 \qquad (9)$$

by the equation connecting the stress tensor components with the deformation tensor components

$$\sigma_{ik} = \lambda u_{ll}\delta_{ik} + 2\mu_s u_{ik} - K_s \gamma (T-T0)\delta_{ik} \qquad (10)$$

by the equation connecting deformations tensor components with displacements:

$$u_{ik} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_k} + \frac{\partial u_k}{\partial x_i}\right) \qquad (11)$$

and boundary conditions

and boundary conditions

$$n_i \sigma_{ij} \Big|_{\gamma_1} = G_j \; , \; u_k \Big|_{\gamma_2} = u_{2k} \qquad (12)$$

where g is the volume force density vector, T0 is the temperature of the body in the undeformed state, K_s, μ_s are the compression and shift modules, γ is the volumetric expansion coefficient. All the coefficients are assumed to be constant within subregions. In the cartesian coordinates the problem is solved both in the approximation of flat deformation and flat stresses. More details, concerning described above part of the package, are given in Ref 2

RF CAVITIES CALCULATIONS

The part of the package intended to calculate electromagnetic field in RF cavities is most developed. Successful usage of MULTIMODE [3] code was the reason to extend the possibilities of the code [4]. In this paper we can not represent formulations for all problem under consideration and give only enumeration and references. All problems are solved for RF cavities with arbitrary cross shape. Cavity is assumed to be filled with several materials with arbitrary (but constant within subregion) permittivities and permeabilties. In the package are realized:

a) calculation of the eigenfrequencies and eigenfields for monopole TM and TE modes in cavities with rotational symmetry [3],

b) calculation of the eigenfrequencies and eigenfields for monopole TM and TE waves and given arbitrary phase shift per cavity in infinitely repeating cavities with rotational symmetry[4,5],

c) calculation of the eigenfrequencies and eigenfields for modes with arbitrary number of variations of the field along azimuth in cavities with rotational symmetry [4,6],

d) calculation of the eigenfrequencies and eigenfields for waves with arbitrary number of variations of the field along azimuth and arbitrary phase shift per cavity in infinitely repeating cavities with rotational symmetry with arbitrary phase shift per cavity [4,6],

e) calculation of the cut-off frequencies and eigenfields for TM and TE waves in waveguides [3],

f) calculation of the eigenfrequencies and eigenfields for TM and TE modes in cavities with translational symmetry [3].

With all possibilities joined in one system, the package is one of most powerful tool for RF cavities simulation in 2D approximation.

METHOD OF SOLUTION

All problems, described above, are solved with using finite elements method in Galerkin formulation. Eight-node quadrilateral isoparametric elements are used. To solve large algebraic system, which is the result of FEM discretization, effective methods [7] are used. In order to solve the algebraic eigenproblem to calculate eigenfrequencies, the subspace iteration method was chosen. It allows to calculate simultaneously several modes nearest to a given frequency value. In eigenfrequencies calculations there are no potential or another spurious solutions. In more details methods of solution, code realization and references needed are given in [2,3,4].

PROGRAMM REALIZATION

Last time all codes, developed before, were fully revised and rewritten in FORTRAN 77. Some improvements in order to extend possibilities and to enhance efficiency of usage, were introduced. The programs of the package can be used not only to solve specific independent problems but also to solve related problems when the output of one task is used as an input for another. To this end a system of information exchange between program modules has been designed. Now the package is computer independent. It is preferable to use codes on computer with core greater then 1 Mbytes.

EXAMPLES OF APPLICATIONS

In Fig.1 is shown the calculated field distribution for fifth TM monopole mode in the third drift-tube cavity of the INR linac. The cavity is more 16 meter long and has 30 accelerating gaps. All real details of the cavity and drift tubes (but without stems) was taken into account. In order to show the precision, let us consider spherical cavity of radius 100 cm with 1cm small metals sphere in the center. Frequency shift due to small sphere for fundamental TM mode, calculated analytically, is 791.8 Hz. Calculated numerically one (grid was with 4916 points) is 791.18 Hz. Relative error of computation this very small frequency shift is $7.8*10^{-4}$, and error of computation cavity frequency is $4.3*10^{-8}$. In the table 1 results for dipole modes frequencies calculations in spherical 2 cm cavity with 1 cm dielectric sphere (1cm, ε =5, μ =1) in the center. Grid was with 435 points. Comparison between numerical and analytic results shows high precision of calculations. Calculated Brilluen diagram for all modes in disk loaded waveguide (Fig. 2a) is given at Fig.2b to illustrate calculations in periodical structures. At Fig.3a the ferrite-tunable cavity is shown. Magnetic field Fig.3b, induced with bias coil, changes the effective of the ferrite ring. It results in change of the working mode (Fig. 3c) frequency. RF power losses in cavity walls give nonuniform heating of the cavity (Fig. 3d) and displacements due to heating (Fig. 3e). Displacements of the cavity walls lead to change in frequency. For this example calculated relative frequency shift due to thermalelastic deformations is 10^{-3} Results, are presented on Fig.3, show application of the package to investigate related processes and are obtained in one run.

SUMMARY

The package for field distribution simulation in 2D appoximation is described. The package is developed ras united system of codes. The usage of the package allows both unify simulation of specific problems and investigate relations between different processes in hardware elements. This enhances efficiency and extends the scope of numerical simulation in the design and study of complex structures.

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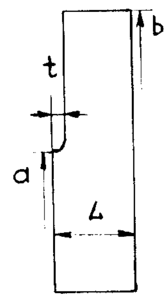
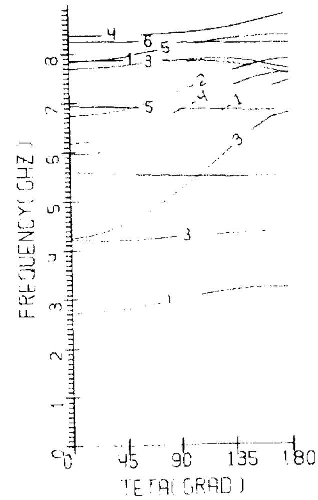
Table 1. Calculation of dipole modes frequencies in the spherical cavity with dielectric sphere.

	analytical result	numerical result	relative error $*10^{-4}$
1	5000.064117	5003.272837	6.41
2	6567.770120	6567.926648	0.24
3	8107.625191	8114.354607	8.31
4	9119.938283	9120.801254	0.95
5	9366.795542	9367.172844	0.40
6	11121.204892	11128.698945	6.71
7	11722.007904	11724.496307	2.12
8	11768.359941	11770.321097	1.66

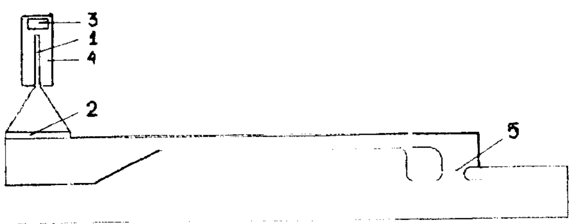


a)

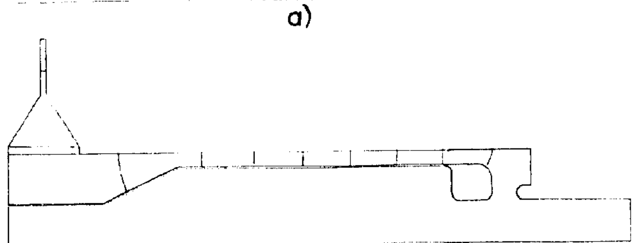


b)

Fig. 2. a) one-half of the cell of disk loaded waveguide, a=1.185 cm, b=4.37 cm, t=0.19 cm, L=1.25 cm, b) calculated Brilluen diagram in the disk loaded waveguide for TM monopole modes (1), TE monopole modes (2), dipole modes m=1 (3), for modes with m=2 (4), m=3 (5) and m=4 (6).



a)



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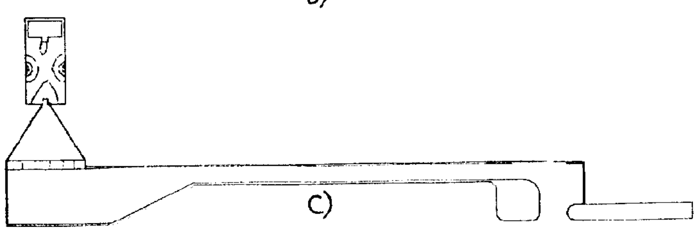

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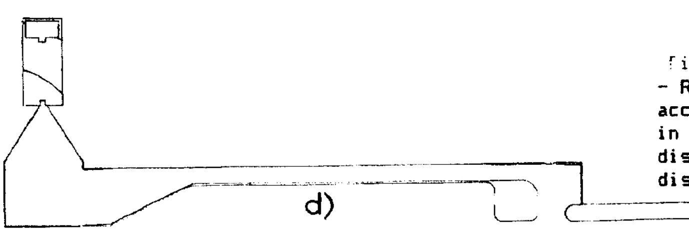
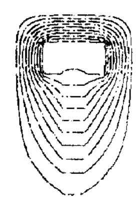


d)



e)

Fig. 3 a) Ferrite-tunable cavity, 1 - ferrite ring, 2 - RF ceramic window, 3 - bias coil, 4 - bias yoke, 5 - accelerating gap, b) electromagnetic field distribution in the cavity, c) temperature distribution, d) displacement distribution, e) bias magnetic field distribution.

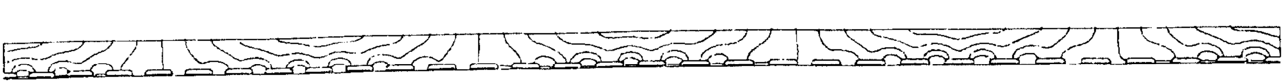


Fig. 1. Electric field distribution for the fifth monopole TM mode in the drift tube accelerating cavity.