Intelligent CAE System of CYCLONE Type Cyclotron Main Magnet and Its Applications

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Abtract

An intelligent CAE method to design main magnet of CYCLONE type cyclotron was developed in order to get reasonable good results in the design even the magnet designer is a biginner.

1. INTRODUCTION

There are many magnetic field computation software packages in the world today to help people in magnet design. The results from the codes are depended on the user's skill and experience very much. Sometimes the results are wrong completely even the input data are right according to the user's manual of the codes. Reason for that is the user lack of the knowledge of the magnet engineering conception. The case can be found in cyclotron magnet design too. To help cyclotron magnet designer get acceptable results a CAE system for CYCLONE type cyclotron main magnet was developed. The intelligent CAE system — CYCCAE allocates and works on VAX−11 / 780 and PC 386. Computation and analysis of the magnetic field were based on the codes which had been used in many practical applications. To make the field isochronous, a CAM program provides a data file designed compatible to numerical control manufacture center to machine the sector shimming bar. The iteration procedure may be necessary when the phase shift is too large to be accepted. Two examples were given to show how CYCCAE works.

2. SCHEME OF CYCCAE

The Scheme of CYCCAE shown in fig. 1 consists of three parts: intelligent CAD, beam dynamics analysis programs and CAM. Because 3D field computation and analysis requires large RAM, VAX / VMS was chosen as the working environment for CYCCAE. In order to make the program work on PC, CYCCAE had to be devided into many independent moduls writen in FORTRAN except an assumbly connected to the graphic interface. Because DOS manages 640 KB RAM only, the program runs as a series of executable files rewriten by MS FORTRAN $_{3.3}$(Graphic interface is rewriten by MS assembler $_{5.0}$). Executable file connections are based on data communication. The files are called by a manage code writen in DOS command. A multi−level menu displays on screen which makes user choose the executable files easily. The main manage menu page is shown in fig. 2.

3. INTELLIGENT CAD

3.1 Intelligent CAD

A designner of cyclotron magnet should possess good background of cyclotron knowledge such as theory, engineering and technology experiences. It is not easy to get a reasonable results for a beginner even he knows how to use the magnetic field software packages. For this reason a library of the expert knowledge was developed to advise beginner how to choose the magnet parameters when some parameters: type of the accelerated ion, final energy etc. are

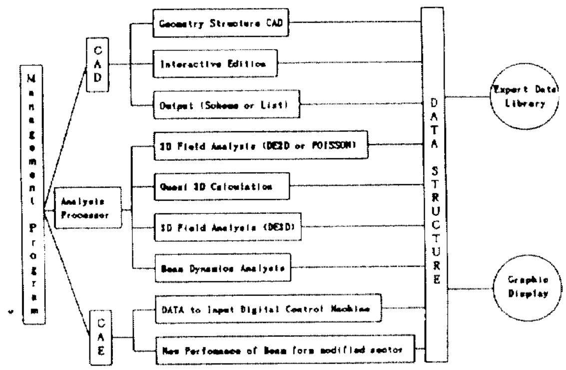

Fig. 1 The Scheme of CYCCAE

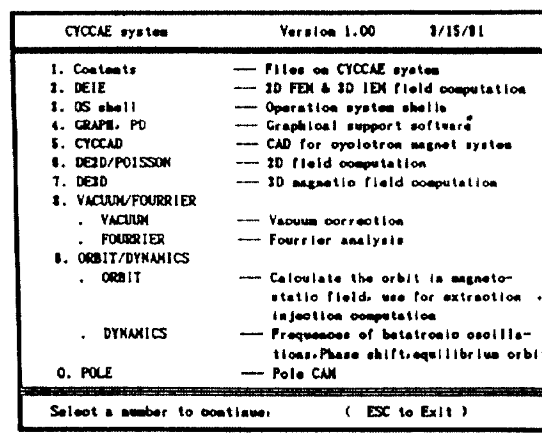

Fig. 2 The main manage menu page

given. For example, to accelerate minus hydrogen particle to 30 MeV, following table will show on screen for user's reference once the program starts out to run:

Table 1 Design Parameters for Main Magnet

Particle Parameters			
Energy E=30 MeV	Rest Mass M_0=938.27 MeV	Acc. Mode MD=4	Charge Numb. q=−1
Magnetic Parameters			
Field in Hill B_H=1.7 T	Field in Valley B_V=0.12 T	Hight of Ring H_{41}=0.15 m	Sector Angle α=54°
Coil and Gap			
Height Width PHW=1.5	Conductor Coil ETA=0.67	Current Density AJ=1 A / mm²	Gap H_1=0.03 m

The parameters on the table can be changed by moving the cursor to a corresponding position or keep the default value. The extraction radius of the accelerated ion should be:

$$R_{ex} = \frac{M_0 \gamma \beta C}{q < B >}$$

From the relation of the R_{ex}, E, and H_1, the library of expert knowledge will provide the radius of sector $R_1$and H_{34}, R_{21}, R_{43}, H_2, $B_3=0.85B_H$, and $R_5 = \sqrt{\frac{S_1}{0.9\pi} + R_4^2}$. R_4etc. will be found by using magnetic circiut analysis. The basic dimensions of main magnet will be determined in one or two minutes on PC.

Two examples: 30MeV and 10MeV proton cyclotron were done by CYCCAE. The basic parameters are very close to existed CYCLONE30 and CYCLONE10 / 5 developed by IBA, but the power needed is slightly reduced.

3.2 *Interactive I / O*

Once the dimensions of the magnet are known, CYCCAE would go on into the interactive graphics system for further analysis or save the data, or print a hard copy etc.

4. ANALYSIS PROGRAM

4.1 *Magnetic Field Analysis*

A group of data files are ready for further analysis detailly after CAD. The most important task is the field computation to make sure whether the magnet can provide the request field including the magnitude and distribution. A group of output data files of the CAD are designed compatible with the input data of field computation softwares. Though the input data files seem large and troublesome, what CYCCAE user does is to choose a number from the menu and strike the key, for example 6 or 7, in the main menu to tell the computer what to do next. The functions of each module are listed in references [1−3]. The computed fields of a cyclotron CYCLONE 30 against the measured are given in fig. 3.

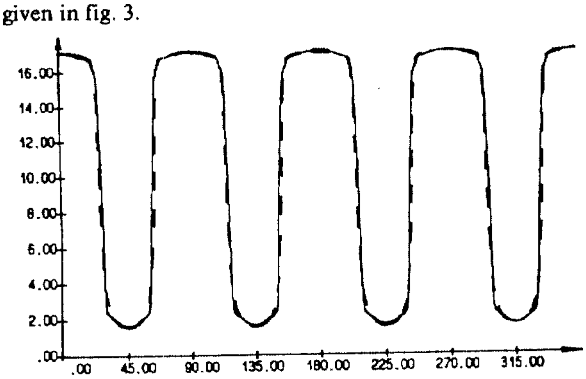

Fig. 3 The computed and measured fields of a cyclotron CYCLONE 30

Though the fields on the symmetry plane both in the valley or on the hill can be found appoximately by 2D field computation, only 3D software can compute the real three dimensional field and check whether the design is acceptable or not. To keep the results with enough precision VAX has to be used for the broblem with more elements and nodes. Data pre−processor and post−processor of 3D field analysis are on PC.

Besides the real three dimensional field analysis, another approximate method called integral algorithm is used for estimation of the magnet basic structure. The method is established by integral of magnetization of the iron elements which can be found based on the fields of the symmetry planes both in the valley and on the hill obtained by using 2D codes. The field at any point can be computed by integral of all sources: conductor currents and magnetized iron elements[4]. In this way, the codes can work on PC because smaller RAM is needed. Of course, it takes CPU time.

So far all informations of magnetic fields both in azimuthal and radial are given and ready for beam dynamics analysis.

4.2 *Beam Dynamics Analysis*

Magnetic fields computed and measured are in atomasphere conditions has to be corrected on account of the particles accelerated in vacuum. The correction formula is:

$$B_{new} = a_1 B_{old} + a_0$$

Where a_0,$a_1$are variable with radius R.

Fourrier analysis was taken for the field before the orbits being computed. The Fourrier coefficients a_n, $b_n(n=1,40)$ and the average field in radial order are shown in fig. 4.

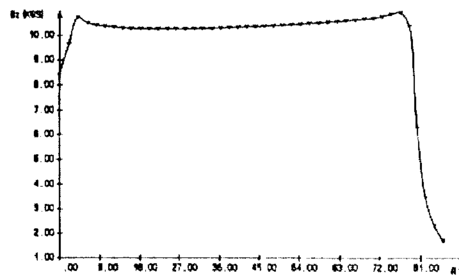

Fig. 4 The average field in radial order

Central and extraction region

There is no electric field in the extraction region. In the central region, the field in the injector electrostatic deflector can be replaced by using an equivalent magnetic field. The orbit is computed by the modul based on the charged particle motion equation in magnetostatic field[5]. The computation results of orbit are shown in fig. 5.

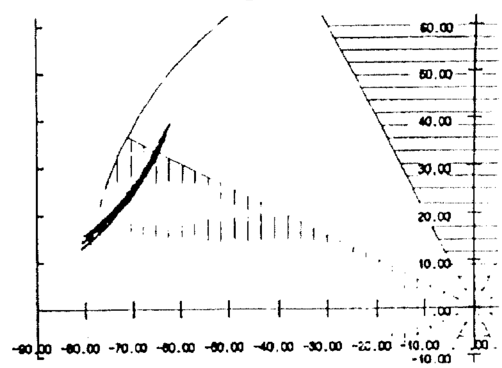

Fig. 5 The computation results of orbit

Phase Shift, Equilibrium Orbit and β Oscillation

There is difference betweem the actual and the ideal isochronous field anyway, so the phase shift. The revolution time t of the charge particle is calculated by integral of motion. The phase shift can be found by comparing t with R.F. period T. The modul PHASE in program DYNAMICS does this calculation. The phase shift is shown in fig. 6.

Not only the phase shift of ion influences the particle can be accelerated effectively to the final energy, but also the β oscillation is important factor too. They represent the stability of transverse motion. According to the transmission matrix $(m_{ij})_{2*2}$of motion, the frequency of β oscillations υ is $\upsilon = \frac{\sigma \times N}{2\pi}$. Where σ is defined by $cos\sigma = \frac{1}{2}(m_{11} + m_{22})$, and

N is the number of magnetic field periods. The frenquency of radial oscillation υ_r is shown in fig. 7. It is calculated by the modul FREN in program DYNAMICS.

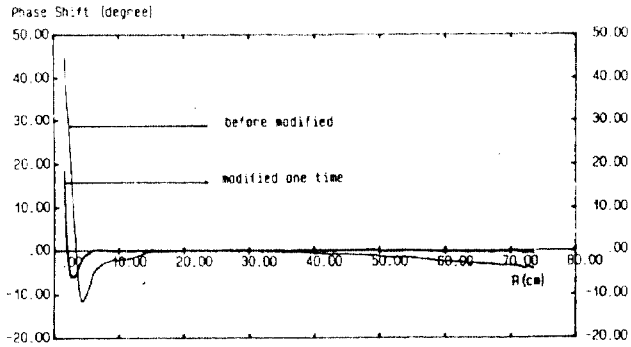

Fig. 6 The phase shift

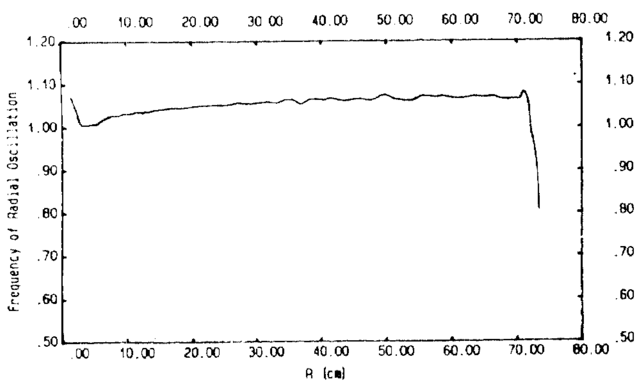

Fig. 7 The frenquency of radial oscillation υ_r

5. CAM FOR MAIN MAGNET

After the iteration of intelligent CAD, magnetic field and beam dynamics analysis, CYCCAE gives the basic dimensions of the magnet. The magnet can be devided into many parts: top yokes, return yokes, sectors and rings. The machanical drawing are made and the machining can be started except the sector edge. The isochronous field will be obtained by shimming the sector edge mainly. Therefore, the sectors remain the same in the machining iteration. What needs to be modified is the sector edge shimming bar. The CAM program was developed for machining the shimming bar. The curved face of the bar is so complex that can be expressed by a group of data (r_i,t_i) only. Based on the (r_i,t_i) and the double-circular spline approximation output data files from CAM program are designed compatable to numerical control manufacture center. After machining and installation, the measured results of magnetic field again used for furture iteration to modify the shimming bar and improve the field. The measured data have the same structure as computed. The phase shift (r_i,p_i) is given automatically by the modul PHASE depending on the measured field, once the uesr choose the function of beam dynamics computation in the main menu. Then the CAM program calculates the correction (r_i,c_i) by the following formula:

$$b_i = 13 + r_i \times (10-13)/(R-0) \qquad \alpha_i = f_i \times p_i \times B_i / b_i$$
$$c_i = r_i \times \alpha_i \qquad t_i = t_i + c_i$$
$$Bi_i = B_i \times (1+p_i)$$

Where f_i is a factor of correction. Bi_i is the field provided by the new bar. The data will be recalled by modul PHASE to check the new phase shift. Iteration does not stop until the field is acceptable.

Fig. 8 shows the installation of CYCLONE 30 magnet and fig. 9 the magnet ready for mapping.

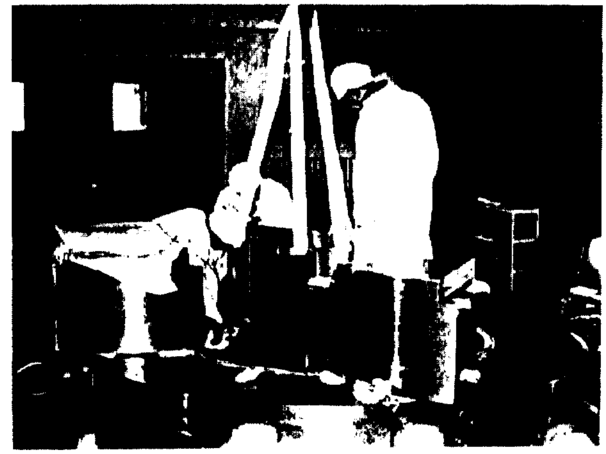

Fig. 8 The installation of CYCLONE 30 magnet

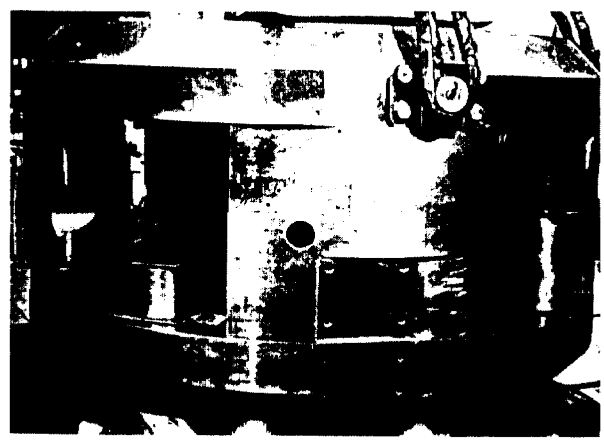

Fig. 9 CYCLONE 30 magnet ready for mapping.

6. REFERENCES

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