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New compact cyclotron design for SPIRAL

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SWG527

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Abstract--The SPIRAL project whose purpose is the production and the acceleration of radioactive nuclei is under realization at GANIL. The new facility uses a cyclotron as post accelerator taking place behind the present machine. The energy range is 2 to 25 MeV/u according to the Q/A factor of the ions. The magnet structure (550 t) is made of 4 independent return yokes and a common circular pole piece (3.5 m in diameter) with 4 sectors. The average induction needed is 1.56 Tesla with hill and valley gaps of respectively 0.12 and 0.3 m. The required field patterns are adjusted by means of circular trim coils located between the sectors and the pole piece.

I. INTRODUCTION

The SPIRAL facility (fig. 1) consists in the production and the acceleration of radioactive ions [1]. It is based on :

- the high energy ion beams at GANIL to produce radioactive atoms through their interaction inside a thick target,
- an ECR ion source to ionize these radioactive atoms,
- a K = 265 compact cyclotron to accelerate the radioactive ions up to 25 MeV/u.

After acceleration, the ions are reinjected through the α spectrometer in the beam distribution line going to the experimental areas.

The cyclotron "CIME" is under construction and the magnet will be delivered on May 1996.

Fig.1 : Layout of the installation of SPIRAL at GANIL

Fig. 2 : Perspective view of the cyclotron magnet

II. MAGNET STRUCTURE

An unconventional mechanical design (fig. 2) for a compact cyclotron was proposed. The magnet is made of four return yokes (instead of two as classical) and a common circular pole equipped with four sectors. The choice of this design was based on magnetic and technical considerations :

- magnetic : the 4th order symmetry for the flux is respected,
- mechanical : the iron weight is better optimized as compared to a conventional H shaped magnet and thus has a lower cost,
- setting up : vertical and lateral dimension well adapted to the present building,
- machining process : parting according to the metal casting possibility (90 t, 4.5 m wide), and accommodation to the manufacture's equipment.
- assembly : weight pieces adapted with the travelling crane capacity.

The cross section of the magnet is shown in fig. 3.

The hill geometry as a function of the radius is shown in fig. 4. The hill is inscribed in a limited angle imposed by the room required for the RF system in the valley.

A damping gap of 15 mm is positioned between the hills and the poles. This allows a better flux distribution and contributes to make the radial field pattern more uniform at different field levels.

The main characteristics of CIME are given in table 1.

Fig. 3 : Cross section of the magnet

TABLE I

Total magnet mass	5500 kN
Overall dimension	6.4 m x 6.4 m x 3.2 m
Average magnetic range	0.75 - 1.56 T
Maximum hill magnetic field	2.1 T
Pole diameter	3.5 m
Hill gap	0.12 m
Valley gap	0.30 m
Main coil (one coil) :	
Nominal magnetic excitation	136000 A
Nominal current	810 A
7 double pancakes of 24 turns	
Conductor	19 mm x 19 mm
Cooling channel diameter	12 mm
Trim coil (one set) :	
Circular coils number	11
Number of turns per coil	8 and 10
Maximum current	800 A (coils 1 to 2), 250 A (3 to 9), 375 A (10 to 11)
Conductors	
	6.5 mm x 6.5 mm ϕ 4.5 mm 8 mm x 6.5 mm ϕ 4.5 mm

III. CALCULATION OF THE MAGNETIC FIELD

The electromagnetic design of the magnet was performed without employing a scale model or a prototype for field studies. Three dimensional field calculations [2] were used in combination with dynamic orbit calculations for isochronous field determination.

The computer used is a SUN SPARC STATION 10 (32 megaoctets memory). With such a machine, the time required to obtain a solution is rather long.

For a 120000 nodes model it lays in the range of five to twelve hours, depending on the number of conductors.

The calculations carried out with TOSCA made it possible to provide the dimensions of the magnet and to optimize the hill geometry (thickness and azimuthal extension) to obtain configurations giving the optimum average field $B(R)$ between 0,75 T and 1,56 T, ensuring good vertical focusing of the beam and minimising the required field corrections.

Fig. 4 : Sector profile

IV. FIELD DISTRIBUTION

The curves of the average main field $B(R)$ are shown in fig. 5 and the field corrections to be carried out with trim coils at extrem field levels are given in fig. 6. It is seen that the corrections do not exceed $\pm 2 \cdot 10^{-2}$ T and the gradients to be corrected are lower than $5 \cdot 10^{-2}$ T/m.

The central region (up to a radius of 20 cm) where the sectors join the central plug still requires further studies, due to the constraints imposed by the axial injection and the choice of the inflector at the machine centre.

Fig. 5 : Main field distribution

Fig. 6 : Corrections to be ensured with trim coils

V. FIELD ISOCHRONISATION

Isochronism laws required to accelerate a given particle are obtained with our code ORBISO, using a field pattern output from TOSCA.

These laws are tuned by means of a set of eleven circular coils enclosed in a stainless steel box located in between the hills and the pole (in the damping gap).

Such a configuration has been chosen in order to provide an easy and low cost realization.

The efficiency is lower compared to coils directly placed on the hills. However the hills acting as filter the residual undulations are lower allowing a minimum number of coils.

The responses of trim coils are very dependent on the main excitation of the magnet and the hill saturation (fig. 7).

These responses are obtained using TOSCA by soustracting the field calculated with main coil and one trim coil excited and the field produced by the main coil alone.

VI. MECHANICAL ANALYSIS

The magnet being composed of four magnetic circuits assembled on the same pole, its mechanical rigidity as well as its supporting have been considered for a long time.

The deformation of the structure considering the relative movements of each plate as a result of the forces acting on it (magnetic forces = 10000 N, gravity, vacuum) was performed at SACLAY[3] using CASTEM (three dimensional code).

The most important result is the effect of the central square structure between the yokes in reducing the camber at the centre of the machine. The use of a 850 mm thick plate (the maximum value possible for the manufacturer) also improved rigidity.

The maximum calculated displacement of the upper pole is 0.5 mm at the centre and 0.2 mm at the outer radius.

The maximum displacement of the lower pole at the centre is 0.06 mm and 0.02 mm at the outer radius.

Though it was not a condition for the rigidity, screwing rods have been added at the bottom of the yokes, to ease the assembly process.

The supporting and the alignment are assumed by means of twelve hydraulic jacks (three of them under each yoke).

VII. MANUFACTURING

In order to assume the 4th order symmetry given by the magnet structure, high level of magnetic properties were specified.

- high induction level in a wide excitation range,
- extra low level of dispersion from piece to piece,
- no field deviation, very clean steel, good compactness (avoidance of inclusion).

TABLE II

MEASUREMENTS MADE AT GANIL ON 40 IRON SAMPLES						
H (A/m)	800	1250	3000	8000	13000	20000
B (T)	1.5216	1.5894	1.6854	1.8185	1.9072	2.0000
σ (T)	0.0085	0.0052	0.0028	0.0055	0.0030	0.0030

Fig. 7 : Set of field produced by a 100 A excitation on each trim coil separately at base field level of 1.56 T and 0.75 T.

The magnetic permeability of the steel was measured on 4 to 6 ring samples per elementary piece. Very small differences have been observed, in fair agreement with the prediction. (table 2).

To reduce the manufacturing cost, just the useful parts of the yokes are to be machined.

All the magnet was ordered to CREUSOT LOIRE INDUSTRIE. We took advantage of their flame cutting thick iron sections possibilities (F.C.M. process) with excellent tolerances (0, + 8 mm for 850 mm thick plates).

CONCLUSION

The CIME magnet presented here have been specially designed to ensure the 4th order field symmetry, to be machined at the lowest price and to optimise the overall dimension. Therefore if a not acceptable first order field harmonic is found, we plan to use balancing coils winded around the return yokes.

The first tests on the cyclotron will start in mid 1997 using stable ions, radioactive ions will be available by the end of 1998.

REFERENCES

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