DIPOLE DESIGN FOR THE EUTERPE STORAGE RING

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Abstract

The magnet system of the Eindhoven synchrotron radiation source EUTERPE (400 MeV) consists of dipoles of unconventional design and construction. Laminated rectangular blocks of transformer steel are fixed together and comprise the dipole magnet (dim. 48x39x35 cm^3). Apart from a small quadrupole component, a field uniformity $\Delta B/B$ of 2×10^{-4} over 4 cm at 1 T is obtained in a 2.5 cm gap. The support system is based on static and dynamic analysis. The resultant "six degree of freedom" manipulator (position accuracy ≈ 0.02 mm) can easily adjust 3 positions and 3 angles of rotation of the magnet. Because of the stroke of the adjustable rods being small (≈ 5 mm), these rods have "elastic hinges" as attachment points. Design and construction have been done at the Central Design and Engineering Facilities of the Eindhoven University. A description of the magnet system, prototype magnetic field measurements and details on the construction, including that of the support system, will be presented.

I. INTRODUCTION

The Euterpe storage ring is a 400 MeV electron ring under construction at the Accelerator Laboratory of the Eindhoven University (NL). The ring is to be used as an experimental tool for accelerator physics studies as well as for the study of radiation phenomena e.g. in undulators. Limited use of the machine for applications of synchrotron radiation is foreseen. This is a university project with somewhat different objectives as for facility projects. Design, construction and testing is an exercise for the accelerator group of the university and their students, with strong backing from the university workshops. The budget for the machine is small, but there is no time pressure for building it. Many components of the ring. e.g. the complete magnet system, are made in the university itself.

Euterpe has a circumference of 40 m and it has a four-fold symmetric lattice with a triple bend achromatic structure, and 2 m long dispersion free straight sections. Various ion-optical modes for different applications can be set by adjusting the focusing properties [1,2]. The injection takes place from a 75 MeV racetrack microtron [3]. The dipole units are small with a small gap of 2.5 cm. This small value may give rise to limiting effects on the beam lifetime; an account on these effects in Euterpe is given in reference [4]. Alignment requirements for the magnet system, together with the alignment procedure is given separately [5]. Table 1 lists the main Euterpe parameters.

II. DIPOLE DESIGN

In the philosophy of the Euterpe ring project an attempt was made to be able to store electrons of the highest possible energy using rather small bending magnets. In the present design of the dipoles the maximum magnetic induction is 1.35 T with a bending radius of 1 m, implying a sagitta of 3.4 cm. This leads a rectangular pole area, and also to a rectangular block shaped C-magnet. In this way, making laminated magnets avoids complicated curving procedures.

It is to be mentioned here that the poles are completely flat: no tapering or pole profiling is performed. The width of the pole is sufficient for good homogeneity of the magnetic field. The actual magnet shape has been determined on the basis of POISSON-calculations. According to this, 14 kA-turns is needed for 1.4 T, where saturation plays a role, with a current loss factor of 6.6%.

A technique applied in the transformer industry is the so-called modular core technique to assemble transformers and chokes [6]. Fabrication of the laminated steel core modules is done by collecting equal parts stamped off a flat steel sheet coil, which is available in a range of standard sizes. The sheet coil contains the adhesive for cementing a module.

Table 1
Main Euterpe parameters

Circumference	40 m
Max. energy	400 Mev
Inj. energy	75 Mev
Beam current	100 mA
Focusing structure	TBA
Superperiods	4
RF frequency	45 MHz
RF voltage	50 kV
Min. emittance	7.4 nm
Pulse length	3 cm
Crit. wavelength	8.3 nm

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Modules to form a transformer or choke are fixed together with rods.

We have bought such modules to compose the C-shaped dipoles. However, the method to fix these together for a complete dipole is different. Because the magnetic forces in the dipoles can be high, clamping the blocks with rods is not possible without unwanted dimensional deformation. Other alternatives where welding the blocks together, or cementing the blocks. Chosen is cementing with epoxy adhesive which is temperature stabilized. Cementing has given very accurate and stress free results. However the film thickness of the epoxy has to be controlled within tight limits.

Since the magnetic properties of the steel sheet depend on the orientation of it (the highest magnetization occurs in the roll direction), the magnetic circuit is optimized by a proper orientation of the laminated modules. In our case 0.35 mm sheet of VM 111-35 iron with a maximum saturation ferric induction of 1.7 T is used. The "pole" blocks with a cross section 12x18.25 cm^2, two mid blocks of 13.5x9.5 cm^2 and one return yoke block of 13.5x39 cm^2 form the magnet. At the pole ends shimming plates have been attached, whose widths will be adjusted for obtaining equal magnetic lengths of all dipoles.

For the coil construction hollow copper conducter of 6x6 mm^2 and a bore radius of 3.5 mm is used. The coil consists of 7x12 turns with a cross-section of 4.5x8 cm^2. The coil weight is 20 kg.

Table 2 gives a summary of dipole data.

III. SUPPORT SYSTEM

The support system is a six degrees of freedom manipulator with the following specifications :- x,y,z stroke ±5 mm ; accuracy ±0.02 mm- φ_{xx},φ_{yy},φ_{zz} stroke ±1° ; accuracy ± 0.005°

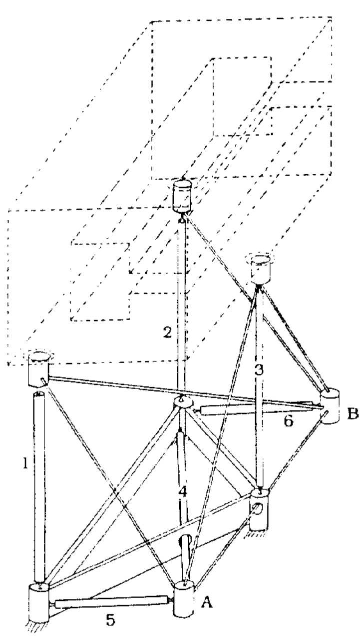

Figure 1 Dipole and support system

Table 2
Dipole data
Type: rectangular, C-shaped, laminated

Size (lxwxh)	480x350x390 mm^3
Total Weight	600 kg
Bending radius	1 m
Sagitta	3.4 cm
Effective orbit length	52.4 cm
Pole size	120x480 mm^2
Gap width	2.5 cm
Coil cross section	4.5x8 cm^2
Magn. field at 75 MeV	0.25 T
Magn. field at 400 MeV	1.35 T
Power @ 400 MeV	6 kW

In classical mechanical design actual and virtual backlashform the Achilles heel of the behaviour. These have to be avoided or, if not possible, have to be limited to close tolerances. Virtual backlash is the positional inaccuracy as a result of friction combined with limited stiffness. Actual backlash is the positional inaccuracy as a result of clearance.

In this case a solution was aimed for in which :
- All components of the support system are attached to one another by means of welding (clearance free).
- The strokes are realized by means of predetermined elastic deformation (no friction and no clearance) of "elastic hinges".

The basis of this solution for the support system is the "solid mass" of the magnet which is supported by three vertical rods (1,2,3 fig. 1). The movement of the remaining system is transduced to the points A and B. This movement is now limited by rods 4,5 and 6. The six rods mentioned can be varied in length. They actually control the six degrees of freedom the magnet has in relation to the outside world.

The mechanical stiffness of these rods predominantly determines the stiffness of the support system. The rods are dimensioned accordingly. The ends of these rods are attached between the mass of the magnet and the outside world by means of "elastic hinges".

Because of thermal effects (a temperature up to 110° C for the magnet could be allowed) the mechanical elements of the magnet and its support system can change in dimensions up to 0.5 mm. These changes may result in excessive mechanical forces. These forces can cause possible plastic deformation and or creep effects in the mechanical elements of the system. Because of that dimensional changes and inaccuracy will occur. Therefore the magnet is attached to the support system with three leaf springs (A,B,C fig.2). The orientation of these

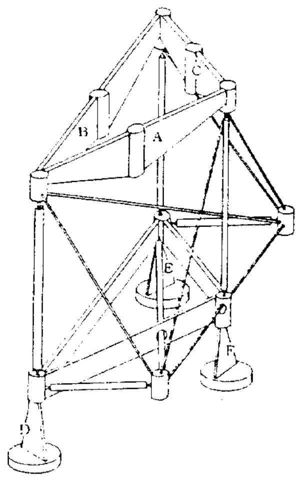

Figure 2 Attachment points support system

springs is such that the relative position of the magnet with respect to the support system remains the same. The same mechanical design concept has been chosen for the attachment of the support system to the ground (D,E,F fig.2).

Mechanical stability is determined with the dimensioning of the stiffness of the support system. A theoretical mechanical resonance frequency of 15 Hz in all directions was chosen (the mass of the magnet is 600 kg). The prototype was measured in three directions and the actual resonance frequency is 14 Hz. Combined with the supposed mechanical noise level of the laboratory these results are adequate for a good dynamical tolerance of place and stability of the dipole mass.

The realized support system has proven to be accurate, cheap to produce and user friendly, even for physicists.

IV. PERFORMANCE & FIELD MEASUREMENTS

Measurements have been performed on a completed prototype magnet, consisting however of modules welded together. This procedure leaves about 20% less area for the return flux, compared to the newer cemented types, sooner leading to saturation effects. Figure 3 shows the excitation curve, as calculated by POISSON and also by measurement. The maximum induction is about 1.6 T; the difference in

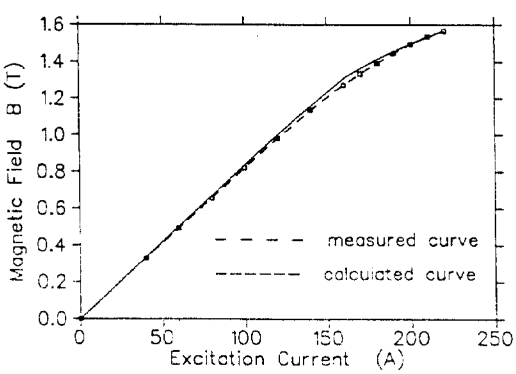

Figure 3 Excitation curve prototype

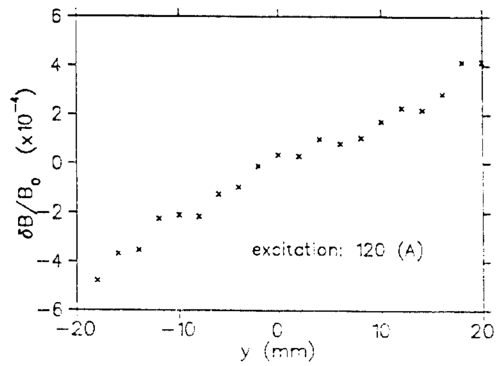

Figure 4 Radial field profile

slope at low excitation for both curves is due to a slightly different gap value. Figure 4 shows the radial field profile at 120 A (1 T). A small quadrupole component is present, which is due to a radially varying gap value. This will be corrected in the cemented versions. Then the expected field uniformity is better than 10^{-4} over 4 cm. The length of the effective field boundary at either side of the magnet is 17 mm. At an excitation of 200 A (1.5 T) a sextupole component of 8 gauss/cm^2 strength is present.

V. CONCLUSION

A modular core technique has been applied for the Euterpe dipole magnets. The assembly of modules and of the overall dipole is completely carried out using epoxy adhesive and resin.

A rigid support and manipulating system has been adopted.

Field measurements on a prototype show the expected performance.

VI. ACKNOWLEDGEMENT

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