

# MASTAC - New Code for Solving Three-dimensional Non-linear Magnetostatic Problems

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## Abstract

A new computer code MASTAC was developed for 3-D magnetic field calculations of different electromagnetic devices contained ferromagnetic, permanent magnet materials and current coils. The methods and algorithms developed in it allow to calculate magnetic field using a personal computer. The results of the calculations of a real magnet and the comparison them with the results of the magnetic measurements are presented.

## I. Methods and algorithms

The method of solving three dimensional magnetostatic problems which is based on the use of two scalar potentials [1]: total in magnetic material and reduced in the rest of the region has been realized in computer code MASTAC. The potential difference at the boundary between the total and reduced potentials is calculated on the basis of functional minimization instead of integration. Such the approach permits to decrease significantly the time needed to calculate the potential difference.

The total and reduced potential calculations are performed by the finite element method on irregular tetrahedral mesh. The method of reproduced sections is used to construct a finite element mesh. The basic mesh is constructed with the algorithm of Delaunay triangulation [2]. This method permits to automate the process of tetrahedral mesh generation.

The magnetic field of currents is represented as a superposition of the fields from tetrahedrons on which the currents is divided. The vector of current density is of a constant value and the same direction in every tetrahedron. The field from a separate tetrahedron is calculated by analytical integration. The methods and algorithms applying to dividing of currents on tetrahedrons are similar to the methods and algorithms used for the construction of a finite element tetrahedral mesh.

A special smooth procedure is used for the calculation of magnetic induction.

## II. Input and Output for MASTAC

The pre-processor gives an opportunity to fulfil all procedures concerning the entering of magnet geometry by means of a cursor driven by a mouse or with the help of a keyboard. During the enter of the magnet geometry its shape is continuously shown on the screen of a display. This allows to immediately see and correct the mistakes in shape of the magnet design. The control of the pre-processor is also realized with a mouse, that originates

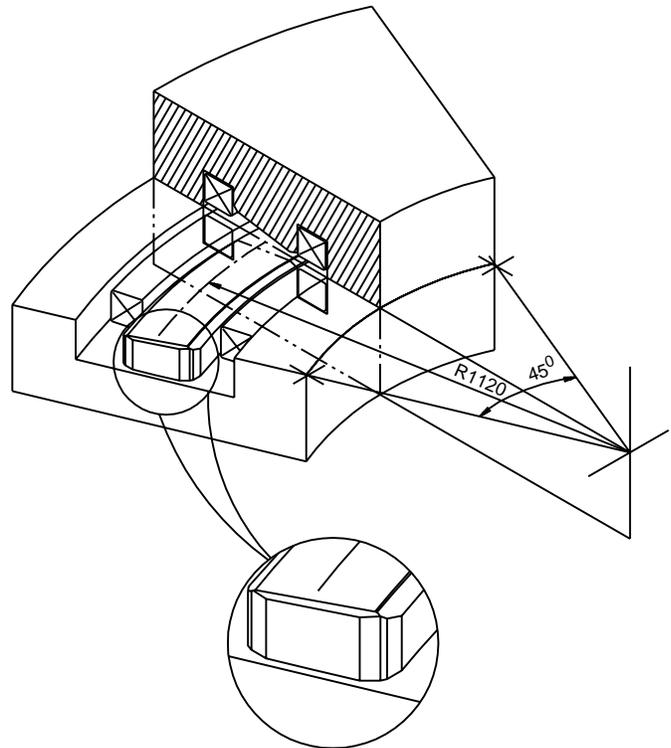


Figure. 1. General design of the dipole magnet.

a very convenient and friendly interface during the work with the computer code.

The graphic means developed in MASTAC allow to construct arbitrary objects in the base section, to put the nodes with local thickening or rarity of the mesh, to edit and deform the local section without changing their topology during the replication of the basic section along an arbitrary vector or arc. In such a manner, one can build a non-surplus mesh for magnets and current coils of curved complicated configuration.

The post-processor allows to take out a potential, magnetic permeability of the ferromagnetic materials, three components and the magnetic induction modulus in the form of graphs, coloured maps and isoclinical lines in an arbitrary cross-section of the magnet.

## III. An example of magnetic field calculation

The precision of magnetic field calculations, its dependence on the number of mesh nodes and the capability of the pre-processor

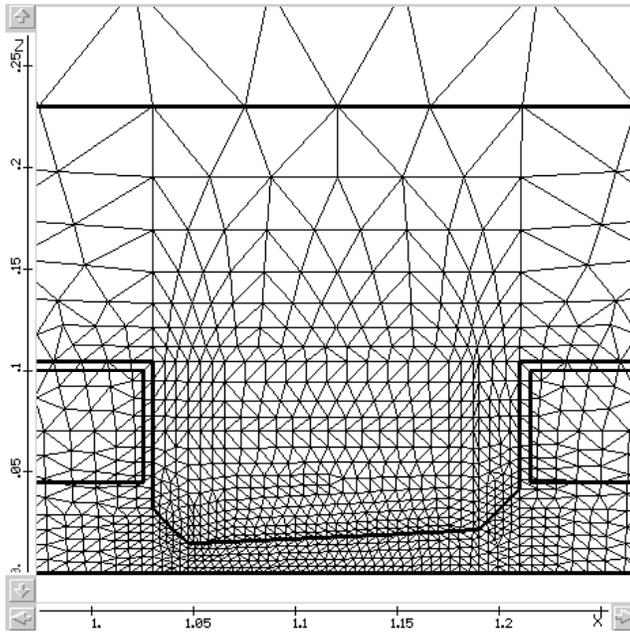


Figure 2. A mesh fragment in the base section of the magnet.

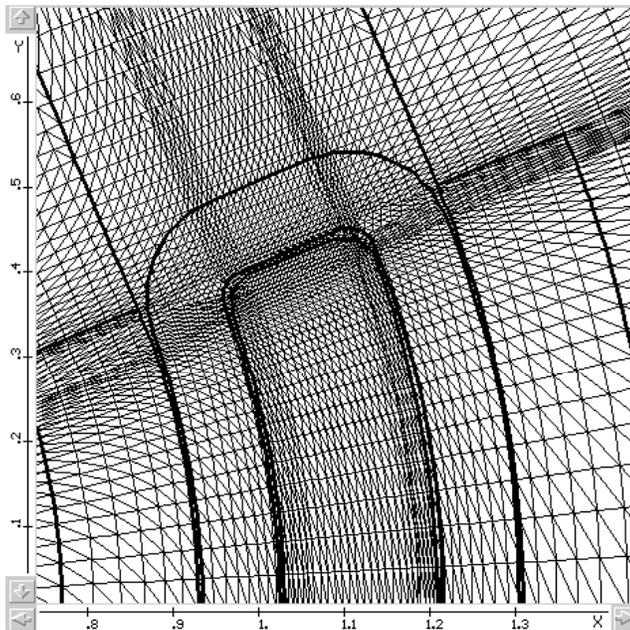


Figure 3. A mesh fragment in the horizontal section of the magnet.

to enter the magnet geometry are illustrated by magnetic calculations of a real magnet sketched in Fig. 1. It is a  $45^\circ$  curvilinear dipole magnet with a radius of curvature of 1.12 m and the complicated profile of poletips, which provides the field index  $n=2.7$  in the 1.2-1.6 T range of magnetic fields. Besides the complicated profile, the poletips have lateral and face chamfers for the reduction magnetic induction in the neck and small chamfers at the corners for a more close fitting of current coils.

As it may be seen from Figs. 2 and 3, the graphic means of the pre-processor as well as the methods and algorithms used in it have allowed to describe, with high accuracy, the complicated

shape of curvilinear poletips and generate automatically of the 3-D tetrahedral mesh (64000 nodes).

The results of magnetic field calculations in the longitudinal and transversal sections of the working aperture, their dependence on the number of mesh nodes are presented in Figs. 4,5,6 and 7 together with the results of the magnetic field measurements. In this figures: dash line - calculation results (16000 nodes), solid line - (64000 nodes), "◇" - experimental results.

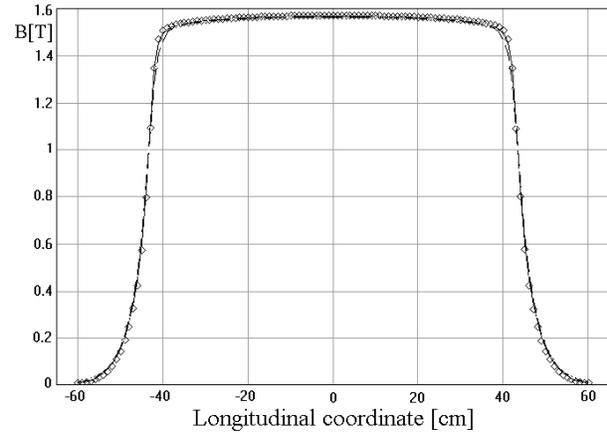


Figure 4. Field distribution of the vertical component in the midplane of the magnet.

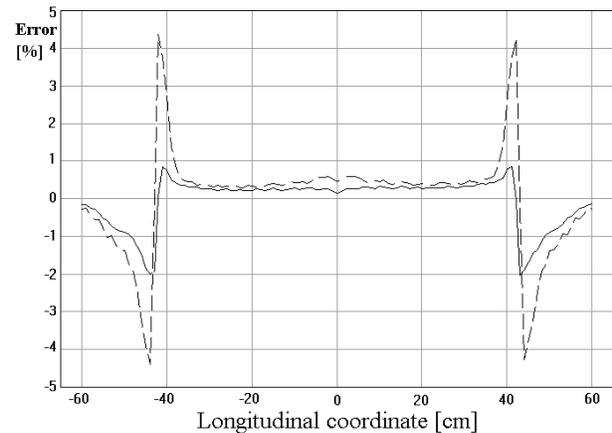


Figure 5. Error in the computed solution as a percentage of the central field.

The calculation times (PC 486DX2-66, 16 MB) depending on the number of mesh nodes are shown in the Table:

Number of nodes	16000	64000
Calculation time	2 h. 30 min.	11 h. 30 min.

#### IV. Conclusion

A new computer code MASTAC was written for 3-D electromagnetic field calculations. The graphic means of the pre-processor allow to enter easily the magnet geometry of arbitrary shape. The use of effective methods and algorithms in computer

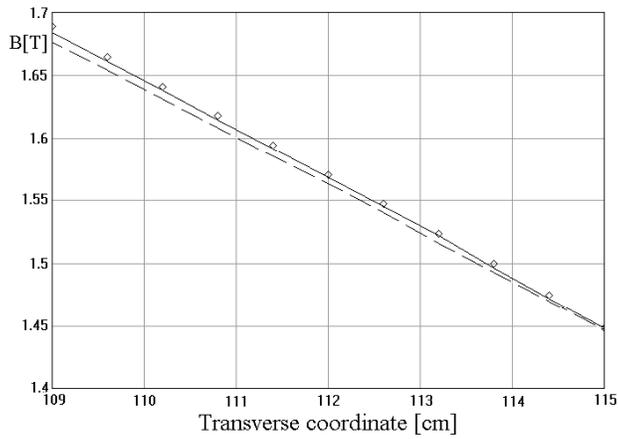


Figure. 6. Field distribution of the vertical component in the midplane of the magnet (middle section).

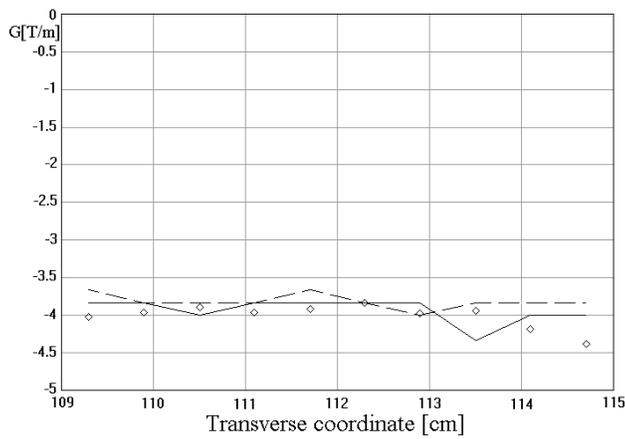


Figure. 7. Gradient distribution of the vertical component in the midplane of the magnet (middle section).

code MASTAC allow to have high precision of magnetic field calculations of any magnets on personal computers.

### References

- [1] J. Simkin and C. W. Trowbridge, "Three dimensional non-linear electromagnetic field computations using scalar potentials," *Proceedings of the IEE*, vol. 127, no. 6, 1980.
- [2] B. Delaunay, "Sur la sphere vide," *Izvestiya Akademii Nauk, USSR, Math and Nat Sci Div*, No. 6, p. 793, 1934.