

# UNDUMAG - A NEW COMPUTER CODE TO CALCULATE THE MAGNETIC PROPERTIES OF UNDULATORS

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## Abstract

A new code for the magnetic design of undulators is under development at the Helmholtz-Zentrum Berlin (HZB/BESSY). The program reads in the geometry and material properties of undulator magnets and iron poles. Magnetic fields, forces and torques, as well as trajectories and synchrotron radiation can be calculated. The code is a stand-alone FORTRAN program, thus, only a FORTRAN compiler is needed to install it. Part of the calculations can be done in parallel threads on computers with several CPU cores. Build-in graphic routines allow to visualize the geometry and the calculated fields, trajectory etc. Results like 3D field maps, field integrals etc. are also written to ASCII files for later use. The code will be published under the GNU general public license. First results and comparison to other codes are presented.

## INTRODUCTION

Although, since years there exists the well established program RADIA [1], the motivation for the development has been, to have a code not depending on third party software or commercial licenses. Another advantage is the benefit of an open source code, that can be adapted to the need of the user.

## INPUT

Up to now, UNDUMAG is controlled by ASCII files. A FORTRAN namelist file with steering variables controls the program run. The magnetic structure is set up by another file defining the geometry of the magnetic items. They can be defined by planes forming a polyhedron, or as rectangular blocks, or by a number of points from which the convex hull is derived. The input files allows to define periodic sections and endpole constellations. Within the geometry input file, parameters can be defined and used to calculate variables of the set-up.

The material properties of the magnets are given by files containing the remanence and  $\mu$  of the easy axis and perpendicular in the case of linear magnets. For non-linear magnets a M(H) curve can be given. For iron, there is a mode for an user-defined M(H) curve and one for an infinite  $\mu$  iron with a saturation value. The later can be used, i.g. to simulate a mirror plate.

The interaction matrix as well as the relaxation results can be read from files of previous run to start with. This allows to refine the segmentation in subsequent runs.

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## OUTPUT

During the calculations, UNDUMAG writes the progress to the terminal where the program is running. A 3D field map including the resulting magnetization of the voxel is written to a data file for later visualization.

Postscript files are generated to show the set-up and the resulting on-axis field, trajectory, field integrals etc. These data are also available as ASCII output files. Further data like the effective field of the undulator and optionally the emitted synchrotron radiation for a given observation point are calculated.

A first step is done to visualize the magnetic items within a CAD program. For this purpose, UNDUMAG writes a VRML file, suitable for many CAD programs. This is under development.

For cross checks a notebook is written, which can be read and processed by RADIA. This ensures that the geometry must be given only once for both codes.

## ALGORITHMS

The input file contains not only the shape of the magnets and poles, but also the segmentation. Generally, all items must be convex polyhedrons. The segmentation algorithm cuts the polyhedrons in the x-, y-, and z-planes. The resulting voxel are treated as individual magnets. During the relaxation procedure, the magnetization and the resulting fields of the voxel are calculated according to the formulas give in [1]. UNDUMAG loops over all voxels until convergence or the given maximum number of cycles is reached. For the considered voxel, a self-consistent magnetization is determined similar to the approach of [2].

Since it may happen that field singularities occur due to boundary effects, the calculation points and optionally the voxel position are randomized by a noise. Symmetry operations allow to reduce the input geometry to an octant of the structure, thus speeding up the calculations and reducing the needed memory.

An damping factor can be used to tune the relaxation process. The convergence is defined at the RMS value of the change in the magnetic field at user-defined reference points. After the relaxation the dipole moments of all voxel are optionally calculated. This is useful for fast calculations of forces and torques or, e.g. to provide a Maxwell-conform parametrization of the field.

## EXAMPLE

Since the written code is quite new, it requires intensive testing and benchmarking. It is rather easy to check many of the program features, e.g. the segmentation, the calculations

of the field integrals, the trajectory through the undulator etc, as long as the relaxation problem is linear. This holds in the simplest case for pure permanent magnets and can be verified by other codes or analytical models. The more interesting cases deal with non-linear materials like iron as it is used in hybrid undulators.

As an example, we consider the design of the CPMU17 currently under construction at BESSY [3]. The pole and magnet design is shown in Fig. 1. This sketch is a drawing of the CAD file written by UNDUMAG. From these main magnets and poles we set up the periodic part of the undulator and add the endpole configuration to adjust the first and second integrals of the fields as shown in Fig. 2. The huge number of periods of the real device are not considered here, since the periodic part is not of interest and requires much computer power.

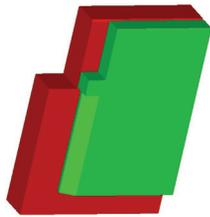


Figure 1: Design of the CPMU17 main poles (green) and magnets (red). The drawing shows only one half of the pole and magnet.

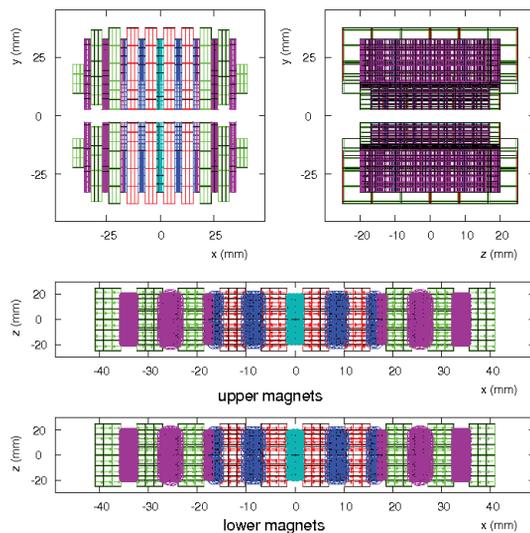


Figure 2: Principal set-up of the CPMU17 poles and magnets. The real device has more than 80 periods. This sketch is an example of the build in postscript graphics of UNDUMAG.

## FIRST TESTS AND RESULTS

We have two approaches to test the reliability of the results. The first is to check their self-consistency. A good test

for the convergence is to plot the M-H values at the positions of the iron voxel and to compare it with the given M-H-curve. This can be seen in Fig. 3 for two different runs of UNDUMAG. The runs differ by the tuning of the relaxation parameters. The green M-H values of the voxels fit the M-H curve significantly better than the red ones from a run with less iterations, no damping in the relaxation process, and different noise parameters. This run seems to be more reliable.

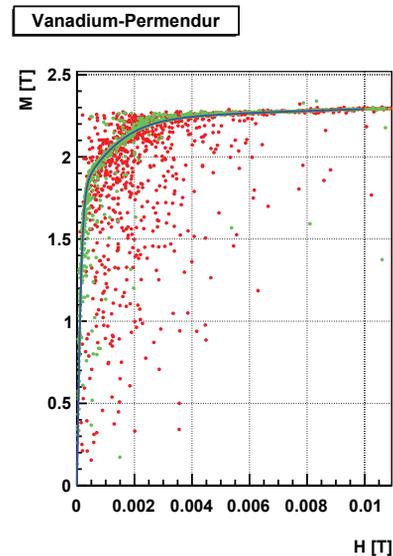


Figure 3: The blue line represents the given M-H curve of the vanadium-permendur steel. The red markers indicate that the corresponding run has not reached the state of a full convergence and self-consistency. The green markers belong to a run with more iterations and the application of the damping factor, that limits the change of magnetization for each iteration.

However, the shown differences do not necessarily result in big differences of the calculated on-axis field of the undulator. This can be seen in Fig. 4. The left figure shows a comparison with a RADIA run (RADIA version 4.29, Linux 64 bit). The right picture shows a detail of the left one for the central pole. The color code is the same as in Fig. 3.

We see that both runs are in good agreement with the RADIA calculations. The difference can be interpreted as the remaining uncertainty of the calculation. But, unfortunately, there is a drawback. The good agreement in the peak fields of the undulator on the sub-percent level is not reproduced for the first integral of the magnetic field. Here we find differences of about 0.5 T mm, which is too high for an undulator with well-adjusted endpoles. This problem is under investigation.

## OUTLOOK

The focus of the development is on the numerical stability and reliability of the iron relaxation procedure. The next steps will then be to speed up the calculations, to im-

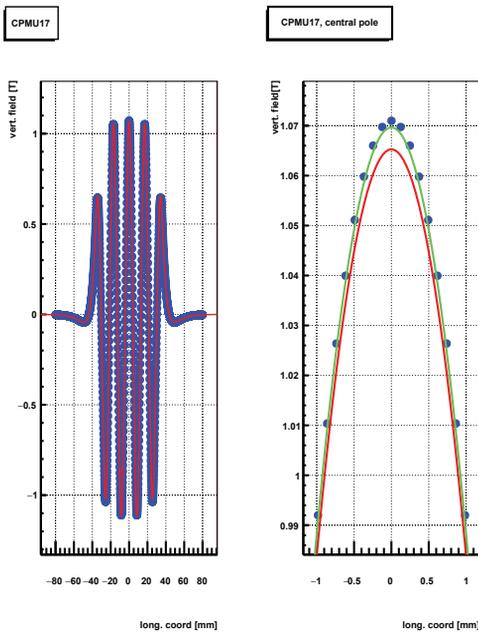


Figure 4: Magnetic field of the CPMU17. The blue markers represent RADIA calculations, the red and green lines those of UNDUMAG for different settings of the relaxation parameters.

prove the CAD support, and to provide an - at least - simple graphical user interface (GUI). A further step will be the implementation of electric currents.

Last, but not least, a tutorial is in preparation, and the code will be made available on a server soon.

## CONCLUSION

The first version of UNDUMAG calculates the fields, forces, torques, trajectories, and synchrotron radiation of elliptical and hybrid undulators. It is in good agreement with the well established RADIA code in terms of undulator peak fields and effective fields. The calculation of the first and second field integrals needs further investigation.

## REFERENCES

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- [3] J. Bahrtdt *et al.*, "Status of the cryogenic undulator CPMU-17 for EMIL at BESSY II / HZB", presented at IPAC'17, Copenhagen, Denmark, May 2017, paper TUPAB026, this conference.