# FRANCESCO AND MAD

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*Abstract*

A new version of the accelerator design code, MAD, was developed by Francesco Ruggiero in 1996. It can provide the function of automatically searching for the dynamic aperture of a synchrotron. With this MAD, we optimized the dynamic aperture of the upgrade project of Beijing Electron Positron Collider (BEPCII) at its R&D stage.

## INTRODUCTION

As we all know, MAD (Methodical Accelerator Design) [1] is a code for circular synchrotron design, developed in 1980's by H. Grote and F. C. Iselin. With the code MAD, people can match a linear lattice of a circular synchrotron, correct chromaticity, optimize dynamic aperture with or without magnetic field errors, calculate synchrotron radiation related parameters, simulate beam-beam effects and beam lifetime, etc. Numerous circular machines were designed by using MAD. The language used in its input file became gradually the normal format in the later codes. In this paper, the new features introduced by Francesco are listed and the application on the BEPCII storage ring is explained.

## NEW FEATURES OF MAD INTRODUCED BY FRANCESCO

It was 1989 when I first used MAD in my work on the Beijing Electron-Positron Collider (BEPC) in the Institute of High Energy Physics (IHEP). After that time, MAD became the main tool of mine to do accelerator study and design. In 1995, I worked in the SL/AP group of CERN as a visiting associate on the dynamic aperture optimization of the Large Hadron Collider (LHC). Dynamic apertures study was one of the most important topics of the LHC design. How to eliminate the effect of sextupolar and decapolar magnetic errors was the key point of the optimization of the LHC lattice. One of my tasks was to investigate the effect of each higher order component of the magnet fields of dipoles and quadrupoles installed around the LHC ring. At that time, I could only use MAD to do tracking one by one particle launched in the machine with different initial positions or divergences. It took the CPU of the SPARC computer about 12 hours for one particle tracking for one million turns of the LHC. When magnetic field errors were introduced, particles with different initial conditions were tracked with 60 random seeds in Gaussian distribution. So, this work was very much time-consuming. It took me about 3 months to get the results of different normal and

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skew field components for the version 4.1 of the LHC injection lattice.

A new version of MAD called "rgo mad" [2] was delivered to the users in the SL/AP group in April, 1996. In this new version, the new command *dynapstart* has attributes common to the MAD commands start and run. It defines the initial conditions of *xstart*, *pxstart*, *ystart*, *pystart*, *tstart*, *ptstart* and tracking options for a single particle. Together with the conventional MAD variables, such as normal mode chromaticities and anharmonicities, these new quantities could be saved in special tables and generated correlation plots. A subsequent call *dynap* is used to invoke tracking, performing an automatic search of dynamic aperture and can then compute several auxiliary quantities according to the additional attributes of *dynapstart*. A fraction *dynapfrac* of the initial betatron conditions gives the final result of the dynamic aperture. In the "rog mad" version, a new command *global* was added to have more capabilities of matching. The newly introduced variables can be used as the global matching constraints for a numerical optimization of machine parameters related to the dynamic aperture.

To my regret, I didn't use these new features of "rgo mad" for the dynamic aperture study of the LHC when I worked at CERN, since I returned my home institute on May, 1996.

## APPLICATION OF THE "RGO MAD" IN IHEP

After I retuned the IHEP, Beijing, China, I was involved in the feasibility study of the project Beijing τ-Charm Factory, which started in 1996 and ended in 1998. This project was not approved by the government at that moment. In late 1998, the upgrade project of the Beijing Electron Positron Collider (BEPC), which is called BEPCII, started with its conceptual design of the storage ring. As an upgraded project, it was hoped to keep the original BEPC tunnel and all the synchrotron radiation beam line exit ports unchanged when it provided beam to synchrotron radiation users in addition to high energy physics experiments. It changed its design from a single-ring machine to a double-ring factory like collider in 2001, shown as Fig. 1. The current BEPCII locates in the original BEPC tunnel, with a crossing angle of 11mrad×2 at its interaction point, when it runs as a collider. A third ring, which is composed of the two halves of outer rings, can deliver beam to the synchrotron radiation users at a higher energy compared to the collision.

In the design of this project, I was in charged of the dynamic aperture optimization for the non-linear lattice of the BEPCII storage ring. According to the experiences got

in the work at CERN, I chose MAD as a tool to study the dynamic aperture of the BEPCII storage ring in the R&D stage.
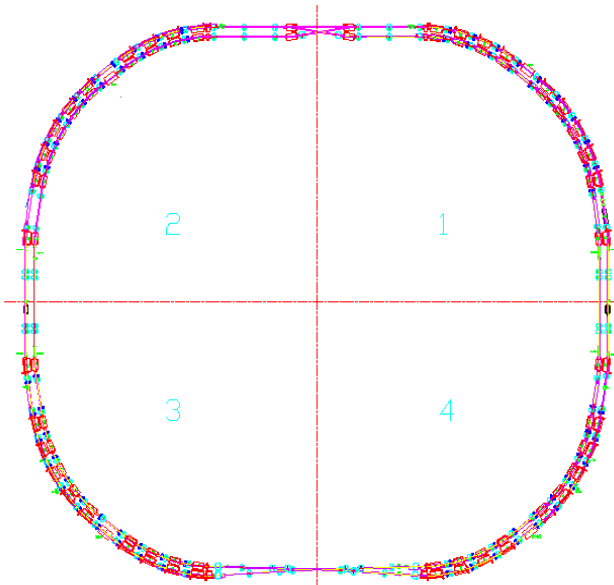


Figure 1: Layout of the BEPCII storage ring

It was naturally for me to have an idea on using the "rgo mad" to do simulation on the dynamic aperture automatically. Fig. 2 gives some of the results of particle tracking with the MAD version of "rgo mad".
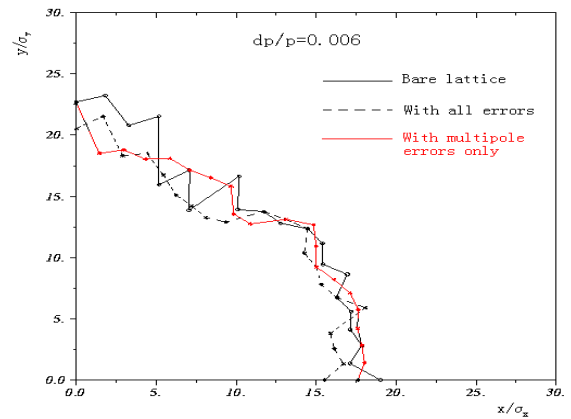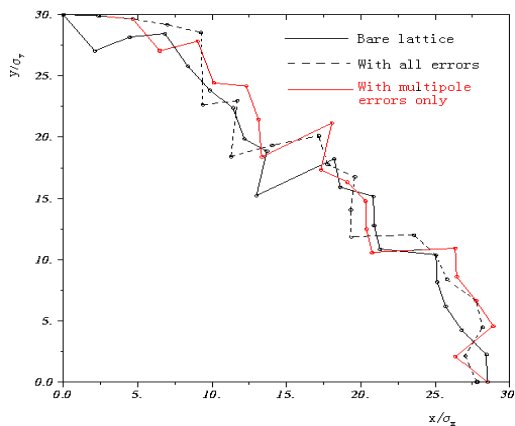




Figure 2: Dynamic aperture results got with rgo mad. Upper: on-momentum, lower: off-momentum

With these new features of the MAD, I did the simulation of the dynamic aperture for the BEPCII storage ring much faster than before. And the project also got the benefits from the contribution of Francesco.

## SUMMARY

It is my honour to know Francesco Ruggiero when I worked at SL/AP, CERN. What impressed me most were his diligence shown in his work, intelligence reflected in his papers, humorous manner to life, and heartiness to everyone. I also benefited from his contributions on accelerator physics. What he did in the field of accelerator physics is forever.

## REFERENCES

[1] H. Grote and F.C. Iselin, The MAD Program, CERN/SL/90-13(AP), 1990.
[2] F.C. Iselin and F. Ruggiero, A Modified Version of the Program MAD to Improve the Efficiency of Tracking Studies, CERN-SL-96-011 AP, 1996.