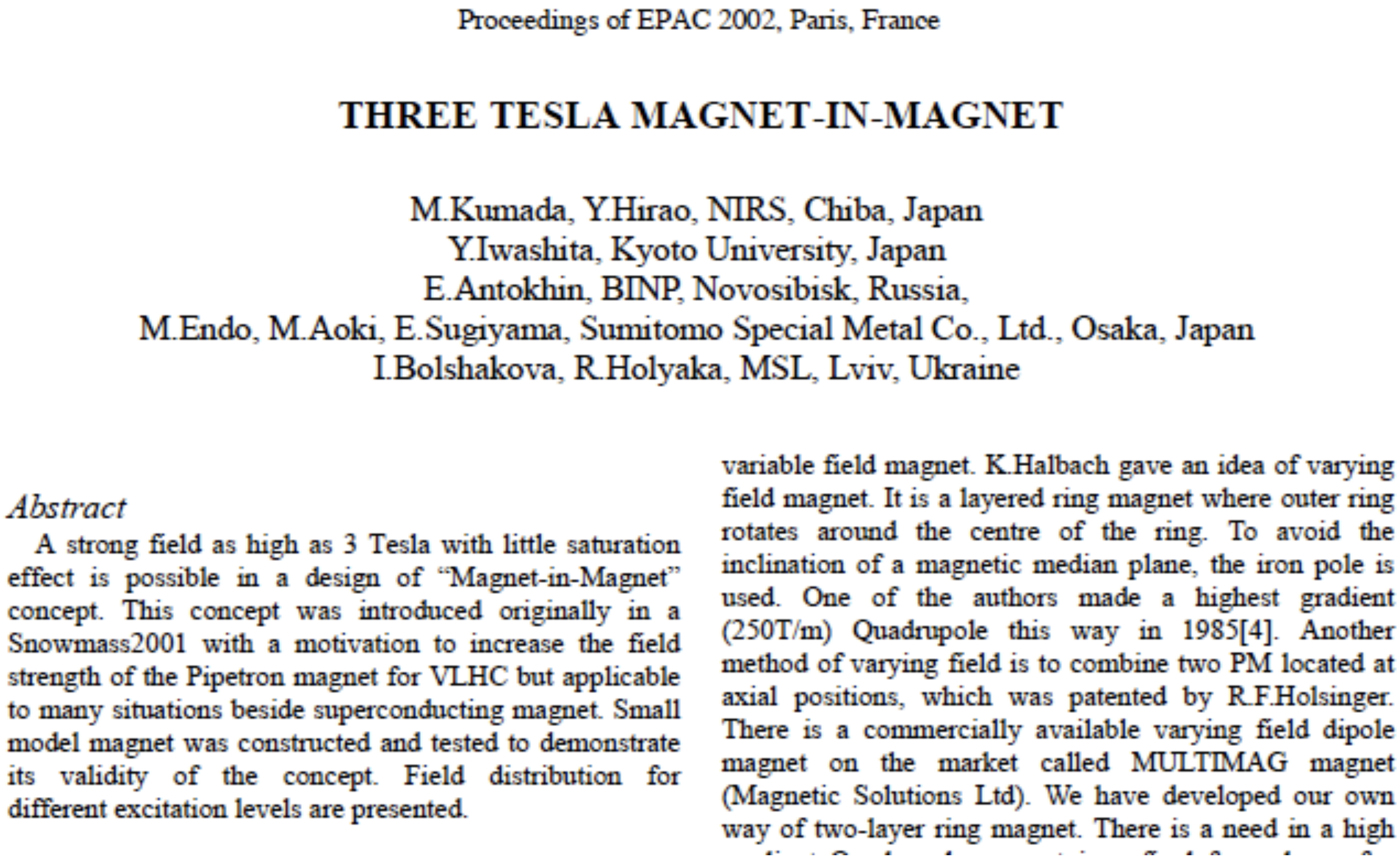
magnet in magnet strikes back

masayuki Kumada
Feynman corporation
NIRS


13th ATF2 project meting



Proceedings of EPAC 2002, Paris, France

THREE TESLA MAGNET-IN-MAGNET

M.Kumada, Y.Hirao, NIRS, Chiba, Japan
Y.Iwashita, Kyoto University, Japan
E.Antokhin, BINP, Novosibisk, Russia,
M.Endo, M.Aoki, E.Sugiyama, Sumitomo Special Metal Co., Ltd., Osaka, Japan
I.Bolshakova, R.Holyaka, MSL, Lviv, Ukraine

Abstract

A strong field as high as 3 Tesla with little saturation effect is possible in a design of "Magnet-in-Magnet" concept. This concept was introduced originally in a Snowmass2001 with a motivation to increase the field strength of the Pipetron magnet for VLHC but applicable to many situations beside superconducting magnet. Small model magnet was constructed and tested to demonstrate its validity of the concept. Field distribution for different excitation levels are presented.

variable field magnet. K.Halbach gave an idea of varying field magnet. It is a layered ring magnet where outer ring rotates around the centre of the ring. To avoid the inclination of a magnetic median plane, the iron pole is used. One of the authors made a highest gradient (250T/m) Quadrupole this way in 1985[4]. Another method of varying field is to combine two PM located at axial positions, which was patented by R.F.Holsinger. There is a commercially available varying field dipole magnet on the market called MULTIMAG magnet (Magnetic Solutions Ltd). We have developed our own way of two-layer ring magnet. There is a need in a high

1 INTRODUCTION

Permanent magnet (PM) has been applied in an accelerator field mostly as undulator/wiggler in a storage ring. There is a myth about PM. They are: The field strength is weak compared to electro-magnet and superconducting magnet. This is because in most cases working point of material is less than half of a residual field B_r where it is 1.2 Tesla for the strongest material of NEOMAX and 0.4 Tesla or so for the ferrite material. PM is only good at small aperture magnet like undulator/wiggler. PM is unstable as magnetization strength depends upon temperature level of a few parts in thousand. Uncontrolable variation of strength of magnetization is a few percent and a high homogeneity required from accelerator performance is difficult.

Recently at Fermilab, large quantity of ferrite magnet was applied to an 8 GeV antiproton storage ring [1]. They made a remarkable progress in PM technology. They have found a solution of the temperature stability problem and homogeneity problem. The field strength of the Recycler PM is only 1.5 kG or so, which is again about 1/3 of a ferrite material's B_r. The strong PM magnet is challenged for Wiggler magnet. 3 Tesla Permanent magnets is so far the strongest [2]. The structure of this PM is the one proposed by K.Halbach where a combination of iron and PM magnet. This configuration can be extended to a circular type dipole magnet. We found out that when the iron pole is driven into a saturated level, the field strength inside the dipole gap is further enhanced [3].

It was found that lowering a temperature of the magnet has a great advantage in increasing the magnetization strength. DC PM can be used for cyclotron or FFAG (Fixed Field Alternating Gradient) accelerator for accelerating charged particle. There is an additional advantage that if a PM magnet can be converted to gradient Quadrupole magnet in a final focus lens of a linear collider. The final focus magnet system where considerable amount of variation of field gradient is required is placed in a huge detector but an available space for the magnet is limited. Ingenious way of mechanical rotation must be invented. We started a project working on this problem [8]. Beside mechanical methods, we propose that a combination of PM magnet with electro-magnet or superconducting magnet as a promising method [8] when field level is around 3 Tesla. We call this type of magnet as "Magnet-in-Magnet". Small model of "Magnet-in-Magnet" is constructed and its quality is inspected. We think there is a possibility of constructing a 3 Tesla "Magnet-in-Magnet" of 30 mm vertical aperture by a reasonable size. This could be applied to a compact synchrotron for medical application or a compact and economic synchrotron radiation ring.

2 MAGNET-IN-MAGNET CONCEPT

The concept of "Magnet-in-Magnet" is introduced first time at the Snowmass01 workshop [7] as an attempt to increase the field strength of the "super" economic superconducting circular collider of the first phase of "VLHC" by factor 2. The magnet is called a transmission line magnet as it is analogous to a coaxial line. This is composed of a single superconducting line sandwitched by two iron blocks. Two gaps are provided. The maximum magnetic fields of 2 Tesla of both signs are generated at both gaps. Due to a balance of the cancelled magnetic forces between the two magnets, the mechanical structure can be simple compared to a conventional superconducting magnet and a "super" great cost reduction is expected. The maximum field strength can not exceed, however, 2 Tesla due to a saturation effect of the iron. A gap size of the magnet is small as 30 mm or so be compact too. A permeability of a rare earth magnet such as SmCo or NdFeB is about 1.05 and a linear superposition of the magnetic field of the permanent magnet to the superconducting magnet is possible. In this way, the magnetic filed of a transmission line magnet could be enhanced by roughly factor two without introducing a saturation effect. In Fig.1, a sketch of a cross section of this concept is shown. We call this type of magnet "Magnet-in-Magnet".

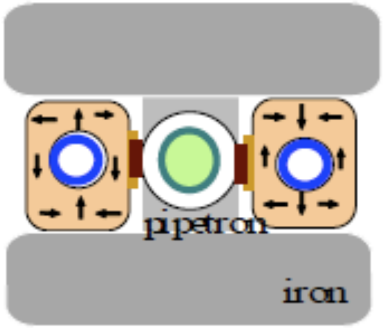


Figure 1. Cross section of conceptional "Magnet-in-Magnet" for VLHC.

3 VARIATION OF MAGNET-IN-MAGNET

There could be variations in "Magnet-in-Magnet". The simple one is a transverse "Magnet-in-Magnet" with electromagnet. This is shown in Figure 2. The extended Halbach permanent dipole magnet is placed in an electromagnet. The field could be varied from 0 to 3.2 Tesla with bipolar power supply.

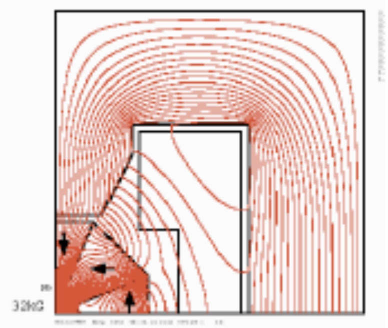


Figure 2. 3.2 Tesla transverse "Magnet-in-Magnet"

estimation by a computer code Mermaid[11] assures its effect is negligible for a frequency of 20 Hz.

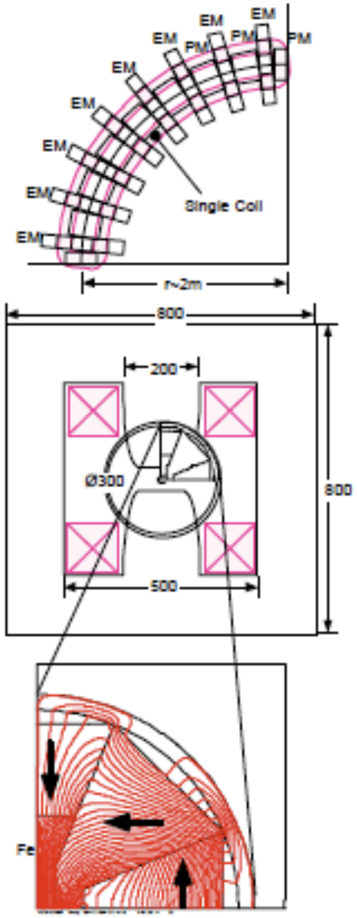


Figure 3. Longitudinal Magnet-in-Magnet (bird view).EM:Electro magnet. PM:permanent magnet.

4 MODEL MAGNET TEST

For a proof of principle test, a small model " Magnet-in-Magnet" were made. The permanent magnet is shown in Figure 4. The flux is squeezed from four horizontal directions. The permanent magnet is placed in an electrical magnet of the gap size of 2 mm x 9mm x 9mm. The horizontal distribution of the excitation

A stability of the magnetic field of the permanent magnet was tested independently by a model permanent cyclotron magnet we are developing.

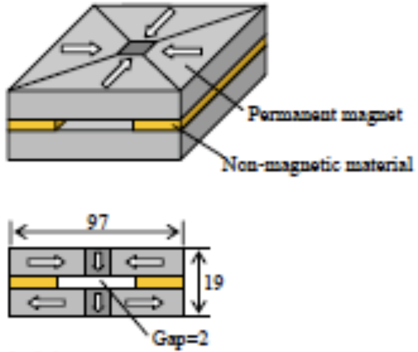


Figure 4. Model permanent magnet
Magnetic pole size is 9x9 and Gap size is 2(in mm).

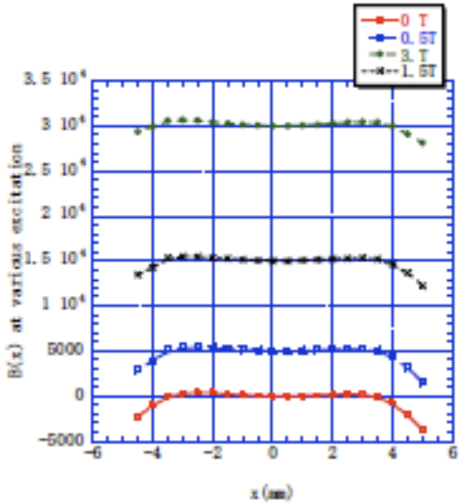


Figure 5. Field distribution from 0 to 3 Tesla.

[3]M.Kumada et al., patent pending. CERN Courier, volume 41,number 7,September 2001,page 9,_M.Kumada etal.,apac01,9/17-21,2001,Bejing,China,M.Kumada et al., MT17,9/24-28,2001,Geneve

[4] M.Kumada et.al, Proc.9th conf .on Magnet technology, Zurich, p.142 (1985)

[5] M.Kumada et.al, PAC01, Chicago, 2001

[6] K.Halbach, IEEE Tran.NS-26 (1979), 3882, K.Halbach, NIM,169(1980)1, K.Halbach,NIM,187(1981), 109, K.Halbach, NIM,198(1982)213.

[7]M.Kumada, "Magnet in Magnet concept" snowmas2001 workshop, Aspen Colorado, June30-July21, 2001, M.Kumada et.al,SAST01,OSAKA, 10/29031

[8] Y.Iwashita, M.Kumada et al., "high gradient final focus Quadrupole for a linear collider", Project between FY2002-2006.

[9] MKumada, patent pending.

[10] M.Kumada and Y.Iwashita, patent pending.

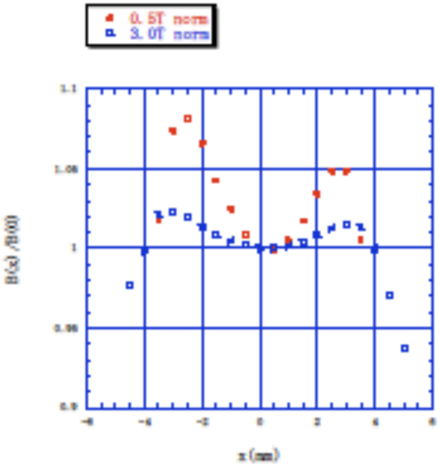


Figure 6. Field distribution at 0.5 Tesla and 3 Tesla.

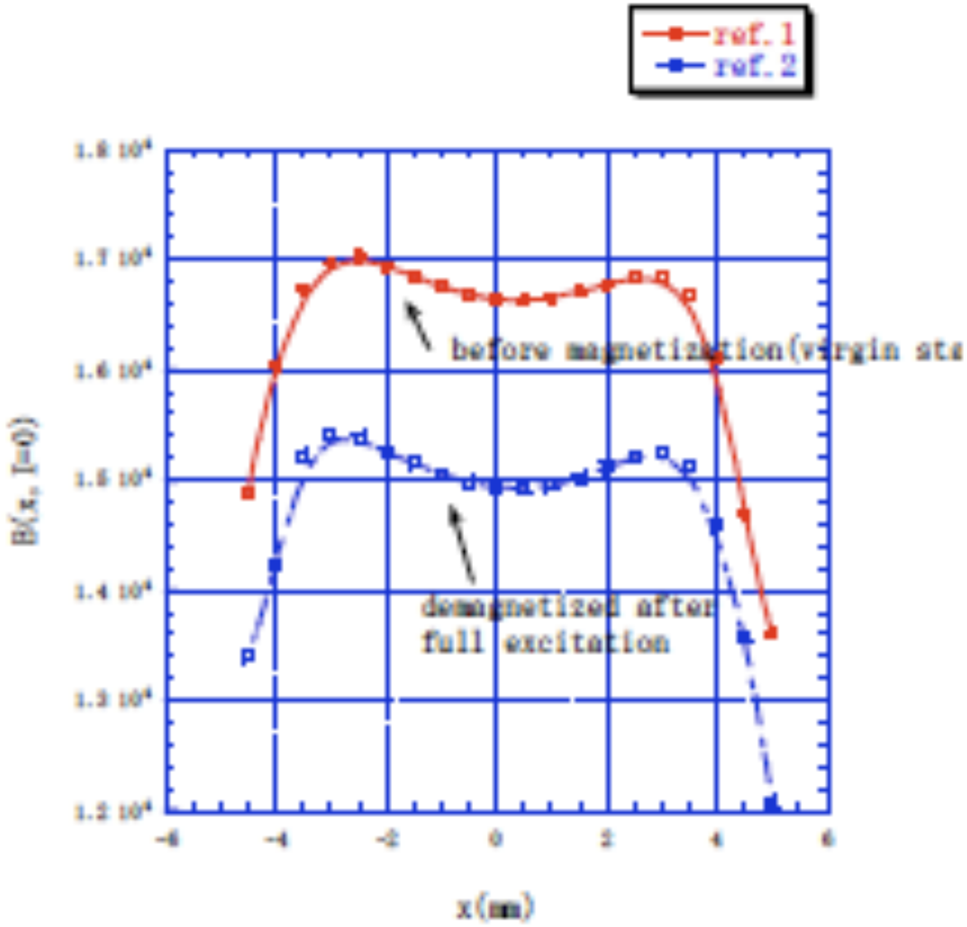
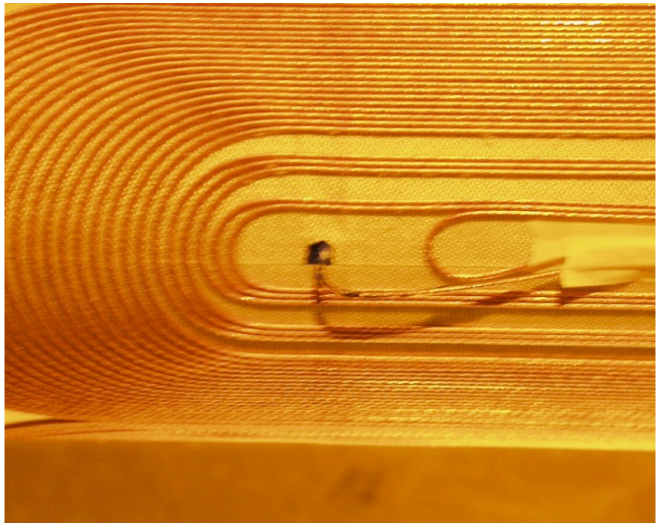
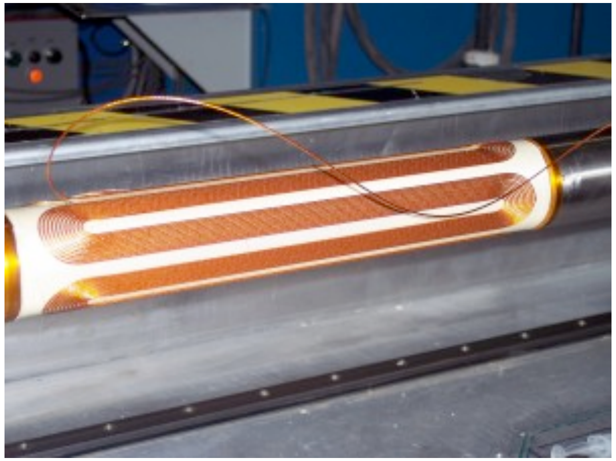


Figure 7. Demagnetization effect

I think the case is solved

Dynamic compensation of multipoles on a vacuum tube





Caution on Magnet in Magnet(MiM):

1) permanent magnet's permeability is 1.05(SmCo,Neomax) not 1.00
2) superposition of the field is violated
3) high field ~ 3 Tesla pole tip is a possible in MiM (hybrid)
4) iron is highly saturated
5) avoid hysteresis effect(full excitation)

Scaling holds to attain for linear integrated field
as
magnet can be designed for a given physical
aperture of fixed length.
This means multiple components of less than
100 ppm is possible
except skew components which can be
dynamically compensated by
correction coils wound on the vacum tube.