Ageing of Permanent Magnet Devices at the ESRF

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Abstract

This paper reviews two typical cases of permanent magnet demagnetization which have occurred during the seven years of X-ray beam delivery at the ESRF.

The first case occurred during the ESRF commissioning and was due to a miss-steered electron beam. The second case was seen over a long period and was due to the routinely produced radiation (i.e. X-rays, associated with the parasitic radiation).

The first process is illustrated with an experiment where various grades of permanent magnets have been voluntarily irradiated with an electron beam in order to study their susceptibility.

I. INTRODUCTION

The European Synchrotron Radiation Facility (ESRF) is a third generation light source which produces brilliant light in the X-ray range. Serving fundamental research and industry, the ESRF provides experimental facilities to a wide community of scientific users in the fields of physics, chemistry, materials and life sciences.

The X-rays are produced by the oscillation of an electron beam passing through permanent magnet assemblies called Insertion Devices (ID) [1] (Figure 1). If this electron beam is lost or miss-steered it could directly hit the magnets placed in the vicinity of its path, and finally demagnetize them.

Figure 1: Magnetic assemblies of an Insertion Device, producing an X-ray beam

Another main cause of demagnetisation is due to the X-rays and the associated parasitic radiation (i.e. principally the neutrons and the Bremsstrahlung gammas produced by the

interaction of the electron beam with the materials). This kind of radiation is produced continuously during the electron beam decay and could, on a longer time scale, seriously damage the ID's permanent magnets.

II. DEMAGNETIZATION ACCIDENTS DURING THE ESRF COMMISSIONING

In 1992, during the ESRF commissioning, two undulators (one on ID6 and one on ID10) were seriously damaged [2]. The electron beam injected from the booster accelerator was accidentally miss-steered and hit the two devices, producing a partial demagnetization of the NdFeB materials over more than half the length (i.e. 0.8 m). This demagnetization probably occurred in less than a few minutes.

At that time injections of fresh electrons were performed with the undulator gap closed. It was decided that from then on, in order to limit damage by the injected beam, the gap of the most sensitive ID should be open during every injection.

A. Demagnetization Bench

Further to accidental demagnetizations, a R&D programme has been initiated [3] to test the sensitivity of various types of permanent magnets when placed in the electron beam's trajectory.

1) Experiment Description

Five different kinds of magnets, produced by the VucuumSchmelze GmbH [4] company, were tested. The main magnetic properties are summarised in Table 1.

Table 1:
Magnetic properties of the studied magnets

Magnet Type	Remanence [T]	Coercivity [kA/m]
VACOMAX 145 (SmCo ₅)	0.85-0.94	1700
VACOMAX 225 HR (Sm ₂ Co ₁₇)	1.00-1.15	1200
VACODYM 351 HR (NdFeB)	1.20-1.30	1200
VACODYM 370 HR (NdFeB)	1.15-1.25	1450
VACODYM 400 HR (NdFeB)	1.05-1.15	1800

For this irradiation experiment, four magnets of each type were simultaneously exposed to the electron beam from the ESRF LINAC. The stack of magnets was placed in the open air, as shown in Figure 2, in such a way that any two samples of a given type were inter-spaced by four magnets of another type.

Figure 2: Schematic of the irradiation setup

The magnets were irradiated without interruption for a period of one hour. The main parameters of the electron beam are summarised in Table 2.

Table 2: Electron beam parameters of the ESRF LINAC

Energy	180 MeV
Beam intensity	50 mA
Pulse length	2 μ s
Repetition rate	1 Hz
Beam cross section	1 mm ²
Power	18 W

The total magnetization of the magnet blocks was measured before and after irradiation, with a *Sinomag* magnetometer. It should be noted that the beam passes through a window of 1 millimetre of steel before entering the air. The estimated dose received by the first magnet of the stack is around 0.7 MGy.

2) Experimental Results

Figure 3 represents the magnetization loss measured for these magnets. The bar labelled Pos.1 corresponds to the sample belonging to the first five magnets of a given grade which receives the electron beam.

Figure 3: Magnetization loss of the magnets according to their position in the stack

This figure clearly shows that the higher the remanence, and the lower the coercivity, the more the magnet is subject to demagnetization from the electron beam. It can also be seen that the demagnetization is different according to the location of the sample in the stack.

Clearly the Samarium Cobalt samples do not show any significant demagnetization [5]. However, their remanence is weaker.

B. Discussion

In order to determine whether gamma radiation by itself can also produce an observable decay in the remanence, many studies have irradiated permanent magnet samples (of Nd and Sm families) with a ⁶⁰Co source [6-7] up to a dose of 14 MGy [8]. Even at this dose level no magnetic characteristic variation of the samples can be measured after irradiation. This is not at all the case for a separate study using other ionizing radiation (such as electrons, positrons), where the first damage can already occur around 0.06 MGy, on Nd-Fe-B material [5]. This shows clearly that the dose absorbed by the material is not the main cause of the demagnetization process [7-8]. The nature of the radiation has a singular effect on this process and therefore the radiation type used for testing the magnets should be as close as possible to the one that the future magnet assemblies will have to sustain.

It is clear [7][10-11] that the radiation damage mechanisms are not fully understood. Nevertheless Talvitie et al [9] explain the mechanism of the flux loss, caused by protons, principally by a local thermal heating. It seems that after entering the sample, the radiation heats the magnet locally. The heating occurred in a very small volume, although the bulk temperature does not increase significantly. This heated region could act, under suitable conditions, as a nucleation centre for a reverse domain, and therefore will lead to the initiation of the demagnetization process.

As it is always possible to remagnetize the magnet after irradiation up to its nominal value, no permanent damage to the crystallographic structure of the magnet occurred[10-11].

III. DEMAGNETIZATION IN ROUTINE CONDITIONS

More recently, it was decided to remove from the Storage Ring (SR) the five year old ID10 undulator (which had replaced the seriously damaged one, presented above) in order to measure the magnetic field of this device in the laboratory [12]. Surprisingly it was discovered that this device was again partially demagnetized as shown in the following figures.

The magnetic measurements were performed in the ESRF ID laboratory. Each magnetic measurement bench is equipped with two measuring devices. One measures the horizontal and vertical field integrals (with a typical absolute accuracy better than 10 G.cm). This measurement is made by rotating a long set of stretched copper wires connected to an integrator voltmeter. The other device measures the horizontal and vertical local magnetic fields along the axis with a three axis

Hall probe travelling along the longitudinal direction of the magnetic arrays (sampling rate of 1 point/mm) [13].

A. Field Integral Measurements

By comparing the 1993 field integral measurements with those of 1997, one can compute the evolution of both horizontal and vertical field integrals, over the full length (i.e. 1.6 m) of the undulator at discrete transversal positions.

Figure 4: Difference of the horizontal and vertical field integrals

As shown in Figure 4, one can see a slight modification of the vertical field integral within the position $x = 10$ mm. There is no clear explanation for this difference. A missing iron shim (which is used to correct locally the magnetic field [14]) or a local demagnetisation could explain this result.

B. Local Field Measurements

The magnetic local field has been measured at a gap of 21 mm, on the magnetic axis of the undulator. The peak field at each pole location has been computed and compared with the original data of 1993.

Figure 5: Normalised losses of the peak field, at a 21 mm gap, for a longitudinal Hall scan

From Figure 5 one can easily see a noticeable loss in the peak field, particularly on the first poles of the undulator as well as on poles # 19 and 20.

A poor coercive field close to its working point in the magnet assembly can explain the presence of a partially demagnetized magnet block further in the magnetic structure (poles 19 & 20). This could be an additional reason for the partial demagnetization of the entry magnet blocks

The first poles of the magnet assemblies showed measurable losses (see Figure 5). In the worse case the loss reached 2% for the first pole at a 21 mm gap. One should bear in mind that this number is much less than was observed in 1992 on the first ID10 undulator (§ II) where losses of more than 10 % were recorded.

In order to investigate in more detail the field losses at the entrance of the undulator, the magnetic field has been measured transversally above the poles of interest for both jaws of the undulator magnet assemblies.

Figure 6: Transverse field homogeneity over the poles 1,2,3,5,10 and 25 of the upper jaw assembly. The dotted curve corresponds to a computed ideal shape.

C. Discussion

In the light of these measurements, the following has been observed:

- the field homogeneity has deteriorated due to a local demagnetisation process;
- this effect decreases progressively as the pole number increases;
- the demagnetisation is not symmetrically localised with respect to the magnetic axis of the undulator;
- 9 the upper magnetic assembly is more affected than the lower assembly.

This long-term demagnetization (over five years) is easy to understand when one considers that the accumulated dose measurements made with Alanine and RPL dosimeters [15-16] over 1603 hours indicate a mean dose rate value of 48 Gy/h in the surrounding first poles of this Undulator (the measurements were made on the electron orbit path). This

represents a cumulated dose of 1.2 MGy received by such magnets throughout the period they were in the SR.

The above accumulated dose, normalised to the integrated beam intensity (expressed in A.h, which represents the circulation of an electron beam which has an intensity of 1 A, circulating during 1 hour) gives a result of 385 Gy/Ah. It is interesting to compare this value with the theoretical one, found in literature [17], which states that for electron storage rings the radiation level in the close vicinity of the beam is found to be in the range of $0.1\text{--}1 \times 10^3 \text{ Gy/Ah}$.

IV. CONCLUSION

Currently, the probability of an «accidental» demagnetization, due to a miss-steered beam, is weak. Every precaution is taken during the injection sequence to prevent such an accident. However, the «slow» demagnetization causes much more concern for the long term. This is because we have to use magnet grades of higher remanence in order to obtain the best magnetic characteristics for ID which also means being highly susceptible to the demagnetization process.

Faced with these facts, and given the strong radiation levels within the ESRF, the mastering of the demagnetisation of the ID has become a key issue for the forthcoming years.

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