IN-VACUUM UNDULATORS AT ESRF

J. Chavanne, C. Penel, B. Plan, F. Revol, ESRF, F38043, Grenoble France

Abstract

Five in-vacuum undulators are currently in routine operation at the ESRF with a minimum gap of 5 mm to 6 mm. The results of the magnetic measurements are presented. The measured interaction with the stored beam (closed orbit distortion, lifetime) are discussed. Three additional devices are at present being constructed including a magnetic structure of hybrid type. They are all dedicated to operation at high photon energy above 50 keV and require an optimum spectrum shimming. The magnet temperature is permanently monitored in all different time filling modes of the ring. An estimation of the heat load deposited by the beam in the flexible input/output transition as well as in the copper sheet covering the magnet blocks is given.

1 INTRODUCTION

Starting beginning of 1999 five in-vacuum undulators have been progressively installed on the ESRF storage ring. Three other devices are being measured in the laboratory and will be installed before the end of year 2003. Their main characteristics are summarized in Table 1. With the exception of the ID11 devices (a prototype), the nominal magnetic length of standards in-vacuum undulators is 2 meters (Figure 1).

Table 1: Status and main parameters of the ESRF in-vacuum undulators.

ID straight	Period [mm]	Magnetic length[m]	Min./Max gap [mm]	Install. date
11	23	1.6	5/30	Jan 99
22	23	2	6/30	Jul 01
29	21	2	6/30	Dec 01
9	17	2	6/30	Dec 01
13	18	2	6/30	Jul 02
30	23	2	6/30	Jul 03
30	23	2	6/30	Jul 03
11	22	2	6/30	Dec 03

Due to baking requirements (120 deg C) and possible radiation damages at small gaps, all devices are based on the Sm_2Co_{17} permanent magnet material. The magnetic structure is of pure permanent magnet type (p.p.m.) for 6 devices. Two devices are based on the hybrid technology (ID11 U23 and ID11 U22).

2 MAGNETIC MEASUREMENTS

The magnetic measurement and field correction methods are essentially derived from the techniques used for conventional undulators. Nevertheless these methods had to be refined when considering the very small gaps (5 mm) and the constraints connected to ultra high vacuum operations. One example is the design of new narrow 3D hall probe keepers allowing field mapping at gaps as small as 3 mm.

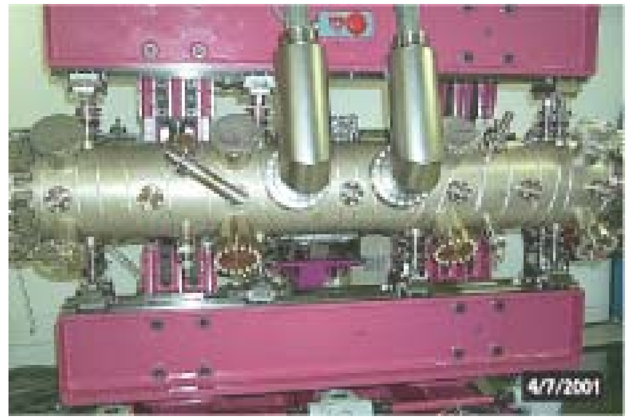

Figure 1: Standard 2 m long ESRF in-vacuum undulator ready for installation

2-1 Multipole shimming

The multipole shimming based on thin soft iron shims as used for conventional undulators is not advisable for in-vacuum device because the shims cannot be glued on the magnet faces. The control of the field integrals is made in two steps:

- Each module containing one or three magnets (two modules make a period) is characterized in field integral. A pairing is determined that minimizes the field integral after assembly. In addition, the field integrals are regularly measured during the undulator assembly and the selection of the next modules to assemble is selected based on the measured field integral.
- After assembly, the field integrals are further tuned using an array of small magnets located at each end of each magnet jaw.

This process is time consuming but allows a high efficiency of field integral corrections. Figure 2 shows the resulting field integral components (gaps of 5 mm and 30 mm) versus horizontal position for the latest undulator (ID30 U23). The associated variation of the on-axis first and second field integrals versus gap is represented in Figure 3.

2-2 Spectrum shimming

The three last devices of Table 1 are expected to operate at high photon energy on the high harmonics of the spectrum (7 to 11). The flux and brilliance of high harmonics are very sensitive to the optical phase errors and require special correction (spectrum shimming). Without any correction the r.m.s value of the phase error computed at each pole is usually in the range of 6 to 8 degrees. Spectrum shimming focuses essentially on the reduction of the r.m.s phase error around 2 degrees at the small gaps (5 or 6 mm). The method relies on the local

0-7803-7739-9 ©2003 IEEE

vertical repositioning (± 100 µm maximum) of the magnet modules. The r.m.s. phase errors after correction as a function of gap is presented in Figure 4 for the first ID30 U23 in-vacuum undulator.

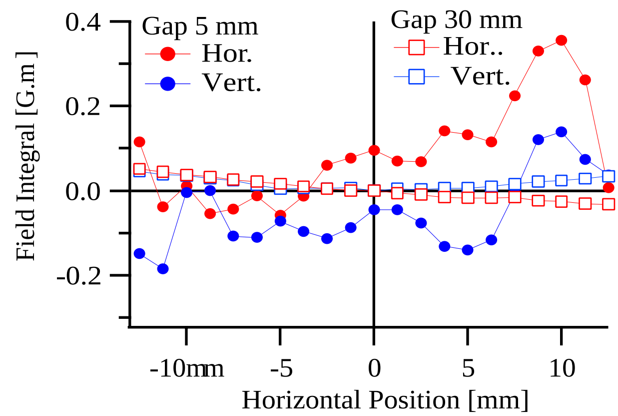

Figure 2: Field integral components versus horizontal position for the in-vacuum undulator ID30 U23 at gaps 5 mm (circular markers) and 30 mm (square markers).

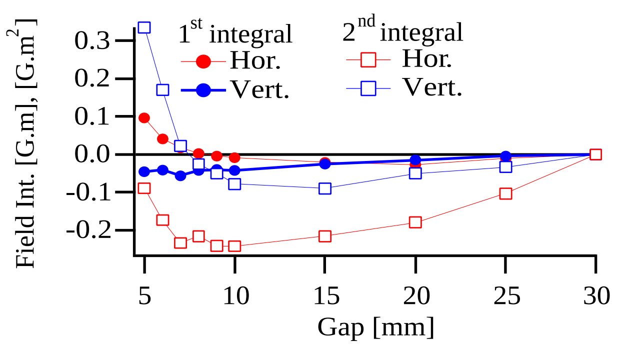

Figure 3:On-axis first and second field integrals component as functions of gap for the in-vacuum undulator ID30 U23.

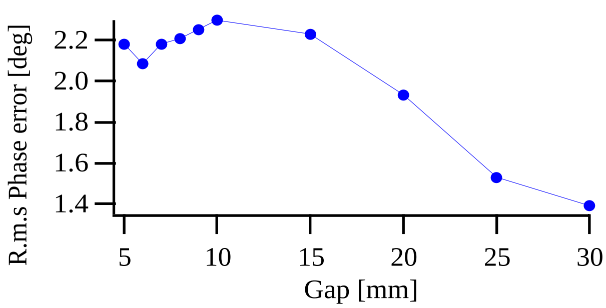

Figure 4: R.m.s phase error as a function of gap for the ID30 U23 device.

3 INTERACTION WITH THE STORED BEAM

3 -1 Closed Orbit Distortions

The most visible interaction of in-vacuum undulators with the stored beam is Closed Orbit Distortions (CODs) induced while varying the gaps. Such measurement is made for all installed IDs on a regular basis (every two months) using an automated procedure. The method involves the reading of all BPMs and adequate fits on data to derive the first and second field integral variations with gap with a reference taken at the opened gap. Table 2 compares the maximum variations of the first and second field integrals in both planes measured in the laboratory and derived from COD measurements for the last four in-vacuum undulators installed. The first integral components ΔIx (horizontal) and ΔIz (vertical) are expressed in G.m and for the second field integrals ΔJz (vertical) and ΔJx (horizontal) the data are in G.m^2. In all cases, the maximum gap is 30 mm (reference gap) and the minimum gap is 6 mm. The COD measurements are in good agreement with magnetic measurements. Such COD results are very similar to those observed for conventional out of vacuum IDs and no active correction needs to be implemented

3-2 Effect on beam lifetime

The effect of in-vacuum undulators on the beam lifetime is another important issue. Lifetime reduction is only visible in the multibunch electron filling modes (uniform and 2* 1/3 filling pattern I=200mA, lifetime 60-80 hours) for gaps higher than 5 mm [1]. For all installed in-vacuum undulators, no effect is visible when closing the ID gap down to 6mm. The reduction of the lifetime remains lower than 10 % when closing further the gap to 5 mm. This effect is very reproducible from one device to another. This is acceptable for future operation of our in-vacuum undulators at the minimum gap of 5 mm. The vertical beta function in the middle of the 5 m straight section is 2.5 m. A straight section can accommodate two in-vacuum undulators segments (ID11, ID30)

Table 2: Measurements of 1st and 2nd field integral variation versus gap for 4 in-vacuum undulators, left part: magnetic measurements, right part: derived from COD.

	Magnetic Measurements				From COD			
ID #	ΔIz	ΔJz	ΔIx	ΔJx	ΔIz	ΔJz	ΔIx	ΔJz
ID9 U17	0.05	0.1	0.09	0.2	0.1	0.1	0.12	0.3
ID13 U18	0.04	0.5	0.11	0.4	0.13	0.4	0.1	0.5
ID22 U23	0.1	0.75	0.1	0.5	0.3	0.9	0.25	0.3
ID29 U21	0.08	0.13	0.09	0.5	0.16	0.4	0.2	0.8

4 HEAT LOAD BUDGET

The ESRF in-vacuum undulators include a water cooling system, as shown in Figure 5. It consists of two separate circuits in thermal contact with the copper blocks ends and stainless steel girder (clamping). The temperature of the magnetic structure is permanently monitored versus time at different positions along the magnetic array (6 for each upper and lower array). The observation of the thermal variations of an in-vacuum undulator is a long time process. Indeed, the global thermal behaviour of the in-vacuum components is governed by a typical time constant of 28 hours which prevents reliable measurements over a few hours.

The water cooling has been disconnected on two devices (ID22 U23 and ID29 U21) for a period of 6 months starting after the summer 2002 shutdown. This experiment had two main interests:

- Evaluation of the efficiency of water cooling
- Estimation of the heat load deposited by the electron beam in the flexible input/output transitions and in the copper sheet covering the magnetic assembly.

Several parameters such as temperatures of the magnet assemblies, ID gaps set by the beamlines, beam current and lifetime were stored in a database with a typical time period of 1 minute.

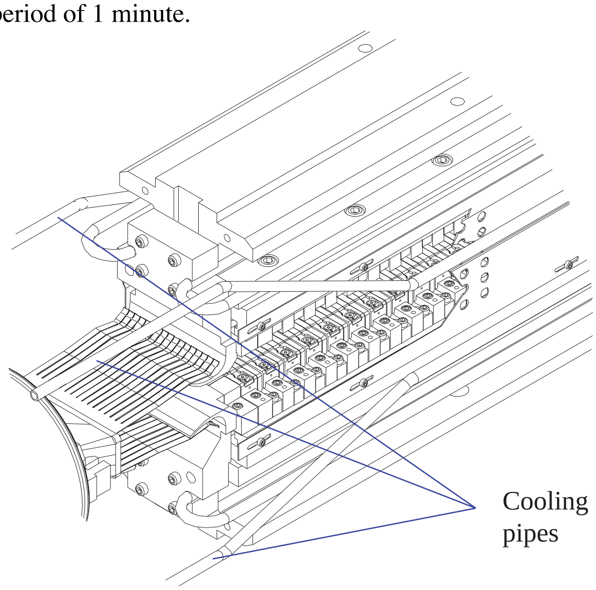

Figure 5: 3D view of the cooling circuit in the end section of an in-vacuum undulator.

Without any water cooling the heat is essentially transmitted to outside through the 16 stainless steel columns connecting the outside main girders and the in-vacuum magnetic assembly. The thermal resistance (≈ 16 deg C/Watt) of each column is the dominant parameter controlling the heat transfer.

4-1 Experimental results

The data extracted from the database concerns only constant gap operation over a period of time larger than four days. Two different electron beam filling modes have been analysed: 16 bunches and uniform filling pattern (992 bunches). Obviously, in these two modes, the beam current is not constant but decreases from 90 mA (200 mA) to 60 mA (170 mA) in the 16 bunches (uniform) filling mode with the periodicity of injections. The temperature of reference measured without current in this experiment was around 24.5 deg C.

The essential observation results are;

- The two undulators have almost the same behaviour
- For the same filling mode the average temperature of the magnet assembly is at its highest when the ID gap is open (30 mm).
- The maximum average temperature of 61 deg C is obtained in the 16 bunches mode (gap 30 mm)

The highest average temperature reached with cooling is 30 deg C in 16 bunches at a gap of 30 mm.

4-2 Empirical model

A very simple static thermal model of the in-vacuum undulator is presented in Figure 6.

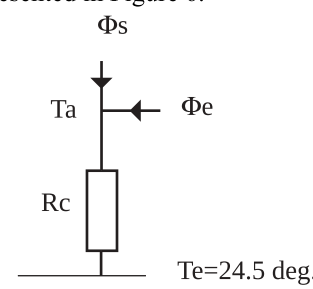

Figure 6: thermal model of the in-vacuum undulator

The purpose of this model is to determine the heat coming from the flexible input/output transitions (Φ_e) according to:

$$\Phi_e = \frac{(T_a - T_e)}{R_c} - \Phi s \qquad (1)$$

T_a is the average measured temperature of the magnet assembly, T_e is the temperature at the end of the columns out of vacuum (24.5 deg. C) and R_c is the thermal resistance of the 16 columns in parallel (R_c=1 deg/Watt). The heat deposited by the beam in the copper sheet (Φs) is evaluated analytically [2] [3] and averaged over beam current and bunch length variations during a beam decay.

Table 3: Empirical heat budget for in-vacuum undulators

ID gap [mm]	Filling mode	Ta [deg C]	Φs [W]	Φ_e [W]
6	16 b	45	6.5	14
6	Unif.	42	2	15.5
30	16 b	61	0.9	35.6
30	Unif.	44	0.6	18.9

The data in Table 3 suggest that the temperature of the magnet assembly is mostly dominated by the heat deposited in the flexible input/output transitions. The higher values for Φ_e at opened gap (30 mm) favour the geometrical wake field as the main source of heat.

5 REFERENCES

[1] J. Chavanne, P. Van Vaerenbergh , P. Elleaume, T. Gunzel ,EPAC 2000, Vienna, p. 2346-2348

[2] J.B. Murphy et al., PAC01, Chicago, p.465-467

[3] K. Bane S. Krinsky, PAC93, Washington, p.3375-3377