DAΦNE TECHNICAL NOTE

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MAGNETIC MEASUREMENTS ON THE SERIES PRODUCTION WIGGLERS OF THE DAΦNE ACHROMATS

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1. Introduction

The measurements performed on the wiggler prototype are described in [1]. Here we present the results of the measurements performed on the other 7 magnets in order to verify the homogeneity of the series production, and to establish for each wiggler the optimum current in the terminal poles in order to make the field integral vanish in each magnet. The measurements have been performed from October 1996 to January 1997.

2. Data acquisition system

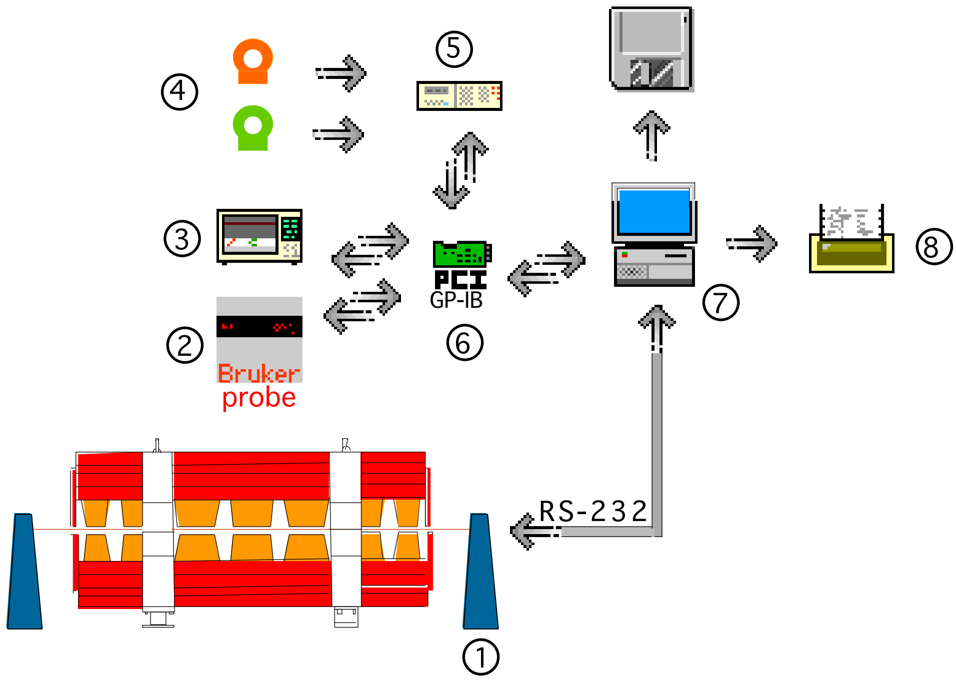
The measuring system consists of an air cushion carriage holding a Hall probe, which travels inside an aluminum guide precisely positioned between the wiggler poles. The carriage is moved by means of a bronze ribbon held under tension between two support towers. The Hall probe can be placed in several positions, precisely determined by dowels on the carriage. The horizontal position of the probe can be changed in steps of 5 mm between ±20 mm, the vertical one can be at the center, +5 mm or -5 mm. The longitudinal position of the probe is controlled by a shaft encoder interfaced to a RS232 serial interface. The sensitivity of the encoder on the longitudinal positions is 0.1 mm.

The "Bruker" Hall probe has an operating field range of ±2.3 T. Its accuracy in the Field Measure Mode |(Bmeas-Btrue)/Btrue| is better than 10^{-4}. The resolution is 50 mG (1 least significant bit).

The output current of the two power supplies, one for the central poles, the other for the terminal ones, is monitored by two precision transducers "Foeldi" 2100A/10V, with a linearity of 10 ppm of full scale and a long term stability of 5 ppm of full scale/500 h. The transducers are read by an HP3457A Multimeter.

The above described instrumentation is controlled by means of a Power MacIntosh 7200/90 interfaced through a PCI board GPIB NI 488.2. The measurements are performed in a temperature controlled environment. The temperature of the input and output cooling water and of the iron are monitored by means of PT100 probes connected to a 4 channels chart recorder and logged by the computer. The block diagram of the measuring system is shown in Fig. 1.

The program which controls all the phases of a typical longitudinal scan of the field in the wiggler is written under the LabVIEW 4.0.1 environment. Its control window is shown in Fig. 2.



1 **Programmable longitudinal positioning of the Hall Probe carriage. The horizontal and vertical position of the probe are set manually by means of dowels on the carriage**

2 **BRUKER Hall Probe**

3 **4 channels Chart recorder YOKOGAWA LR4110 equipped with PT100 thermystors**

4 **FOELDI current transducers**

5 **HP 3457 A Multimeter**

6 **NATIONAL INSTRUMENTS interface PCI GPIB NI 488.2**

7 **Power MacIntosh 7200/90**

8 **Ink Jet printer HP**

Figure 1 - Block diagram of the data acquisition system

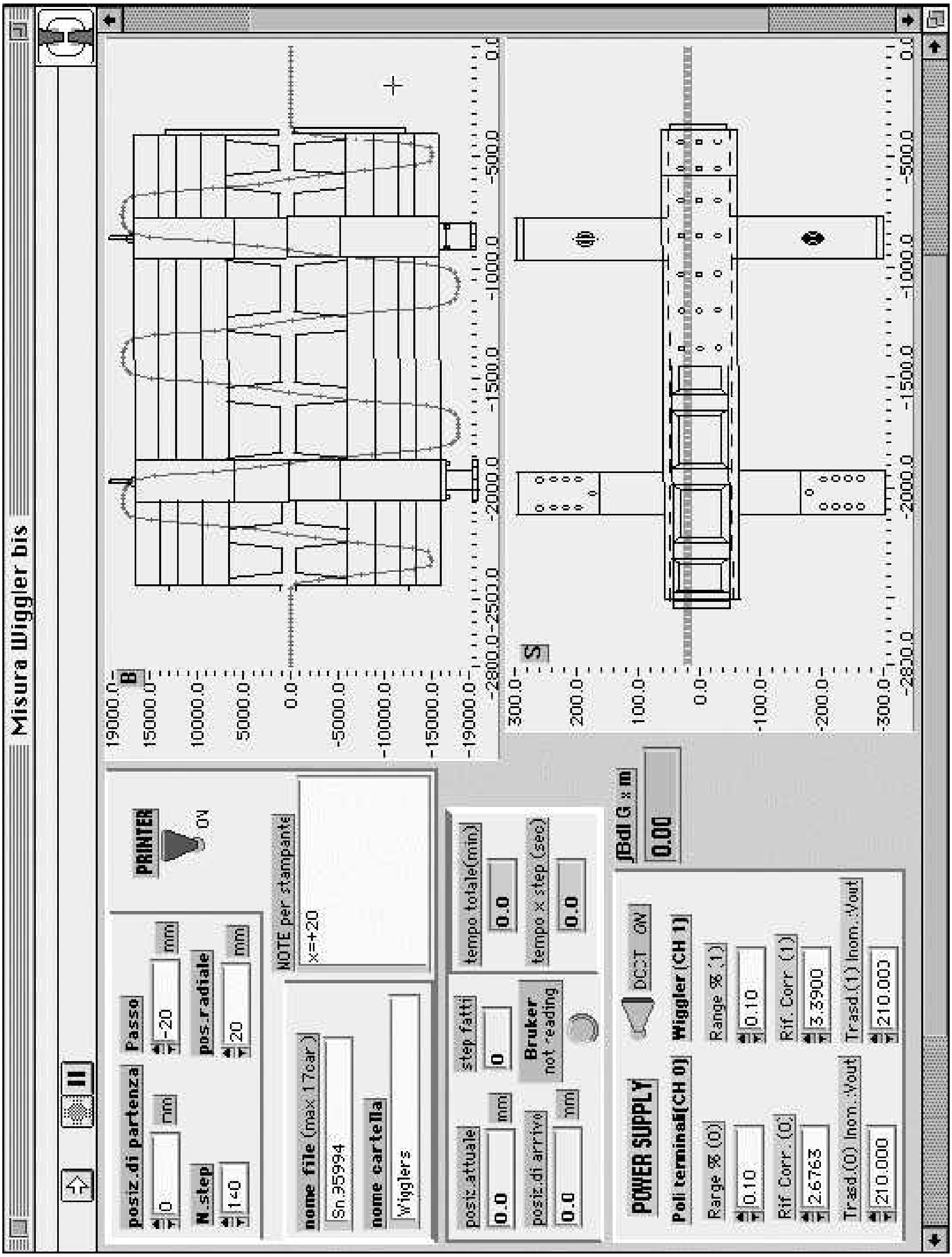


Figure 2 - LabVIEW window of the data acquisition control program

3. Magnetic measurements on the prototype (Serial#95989)

Since the prototype magnet had undergone some minor modifications at the factory after the initial measurements on the prototype [1] and also due to the long time (more than two years) elapsed, it was decided to perform some check measurements on it.

Already from the first scans it appeared clearly that the reproducibility of the overall field integral was rather poor. Table I summarizes the results obtained during the first five days at the nominal operation point [1], namely with 711.9A in the central poles and 562.0A in the terminal ones.

Table I - Field integral (Gm) over a longitudinal scan in the wiggler (I_{CP} = 711.9A, I_{TP} = 562.0A)

Date	on axis	x = +20 mm	x = -20 mm
14/10	-0.96	-5.93	
15/10	+11.51	+6.48	
17/10 #1	+4.89		
17/10 #2	+4.70		
17/10 #3	+5.59		
17/10 #4	+8.68	+0.31	
18/10 #1	+15.54		
18/10 #2	+11.03		
18/10 #3	+9.58	+6.24	+8.20

A first conclusion drawn from these preliminary measurements was that the field integral in the wiggler could depend from the temperature of the magnet, which requires a rather long time before reaching the thermal equilibrium with the temperature-controlled environment.

We recall that the wiggler is built as a solid iron yoke with removable poles divided into an upper and a lower half supported by frame shaped aluminum structures.

It was therefore decided to monitor the temperature of inlet and outlet cooling water and of the iron by means of thermystors placed on the central pole and near the hoses of the cooling system.

However, this was not enough to explain the difference between the results of the scans taken in different days, and we concluded that unpredictable malfunctions of the shaft encoder system could lead to wrong correlation between measured field and longitudinal position of the probe. A computer code was therefore written to analyze in detail the output of the measuring system in order to find the discrepancies between different scans. Figure 3 shows a typical scan on the wiggler axis, with the symbols used in the following to explain the physical quantities evidenced in the program output.

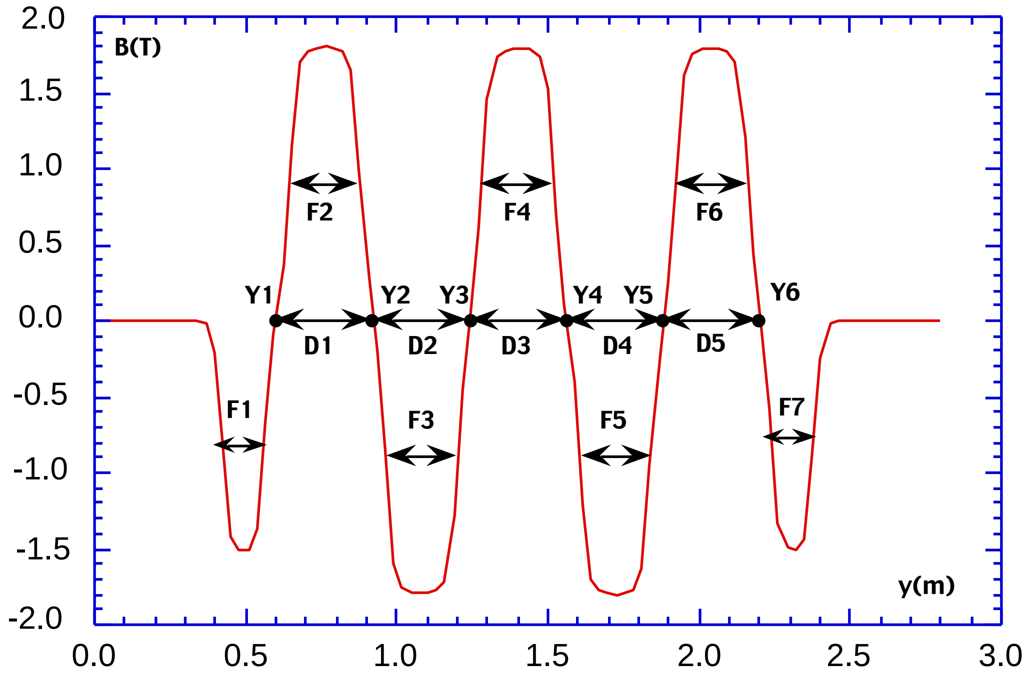


Figure 3 - Definition of the variables calculated by the analyzing code.

The longitudinal positions where the field goes to zero are calculated by interpolating linearly between the two nearest measured points and are indicated with Y1÷Y6. We indicate with D1÷D5 the distances between the adjacent positions Y. The program also finds by means of a parabolic fit to the highest measured field points the position and the amount of the field maxima in the seven poles. Taking the half values of these maxima the longitudinal positions of the half maximum are again found by linear interpolation in order to determine the full width at half maximum for each pole, which are indicated with F1÷F7. Finally, the code computes the field integral in each pole (I1÷I7) by means of a cubic interpolation: for the central poles the integrals are taken between the corresponding values of Y, for the terminal ones the limits of integration are the beginning and the end of the scan and the first and last value of Y respectively. Figure 4 shows the temperatures monitored during the whole day on October 22, 1996: the water of the cooling system reaches its steady state after about two hours, while the iron saturates very slowly and becomes constant only after about 8 hours.

It was therefore decided to adopt the following measurement procedure on the series production magnets, in order to find the best possible compensation for each magnet:

- Perform three scans on the wiggler axis, interleaved by two hours, in order to have the last scan about 4 hours after switching on the power supply (the time duration of each scan is ≈ 40 minutes).

- After the last scan on axis, measure the field along the wiggler at an horizontal distance of 20 mm on the right and 20 mm on the left with respect to the symmetry axis, in order to estimate the sextupole contribution.

- Monitor the temperature of the central pole, inlet and outlet cooling water, during the whole duration of the measurements.

- Run the analyzing code on the five outputs in order to find anomalous variations between the different scans.

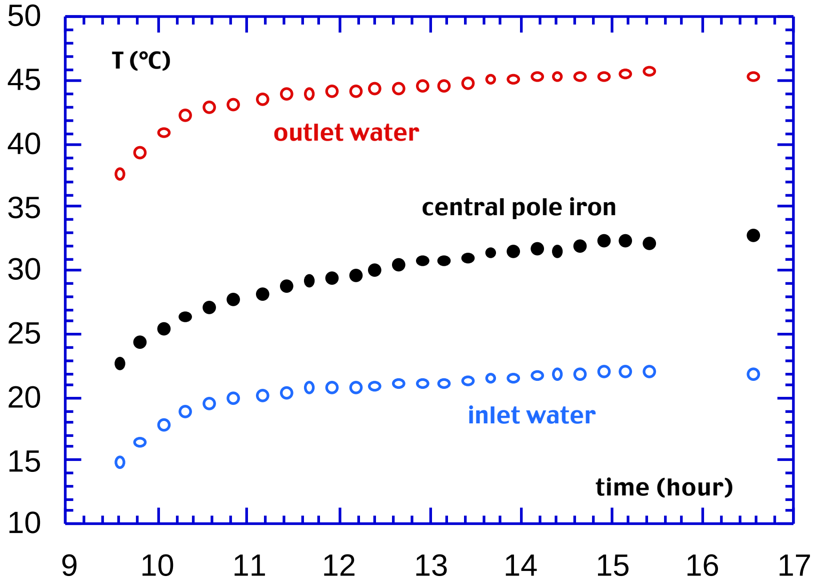


Figure 4 - Wiggler temperature during a full day measurement

Figure 5 shows the overall field integral measured in this way on the prototype. The last two points represent the scan at ±20 mm from the axis and are therefore separated from the others. It can be observed that the integral on axis exhibits a smooth behaviour, compatible with the variation of the iron temperature during the five hours elapsed between the first and last scans. The measurements at ±20 mm from the axis, on the contrary are rather different (≈ 4 Gm) between each other, while they were very similar according to the measurements on the prototype in 1994 [1], where the difference between the integrals on axis and at 20 mm was around 6 G. The last measured point was therefore a good candidate in order to detect a malfunction in the measuring system. In the following we show, as an example, the result of the analysis performed on the different scans, finding out the reasons for the anomalous value of the last point.

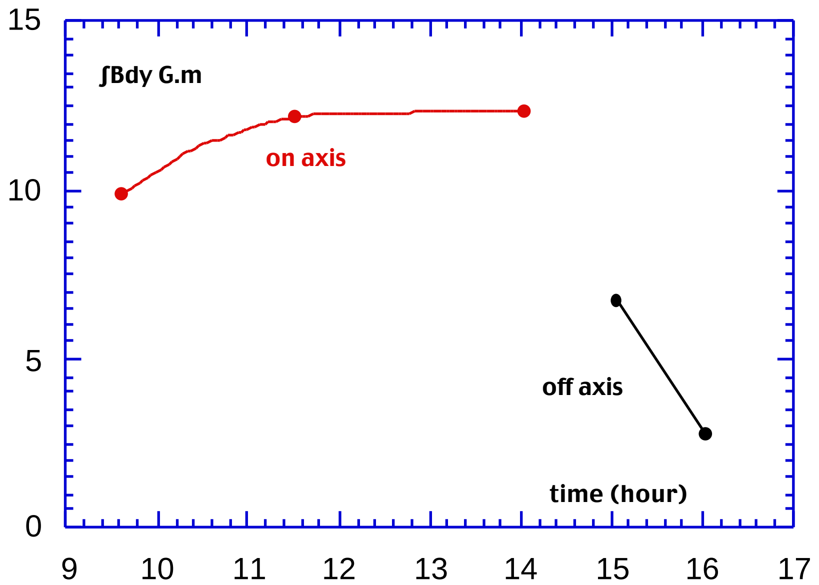


Figure 5 - Field integral of Serial#95989
(the last two points are taken @ ±20 mm from the axis)

The values of the field integrals in the central poles and in the terminal ones are shown in Figs. 6 and 7 respectively. The points connected by full lines represent the positive poles, the dotted the negative ones. While the measurements on axis exhibit a smooth variation, in those at ±20 mm there are differences of the order of 5 Gm between the scans at +20 mm and -20 mm for the central poles #2 and #3 and in both terminal ones. However, the effect in the central poles approximately cancels out due to the different sign of the poles, while in the terminal ones they add up, giving a larger negative integral in the last scan at (+20 mm).

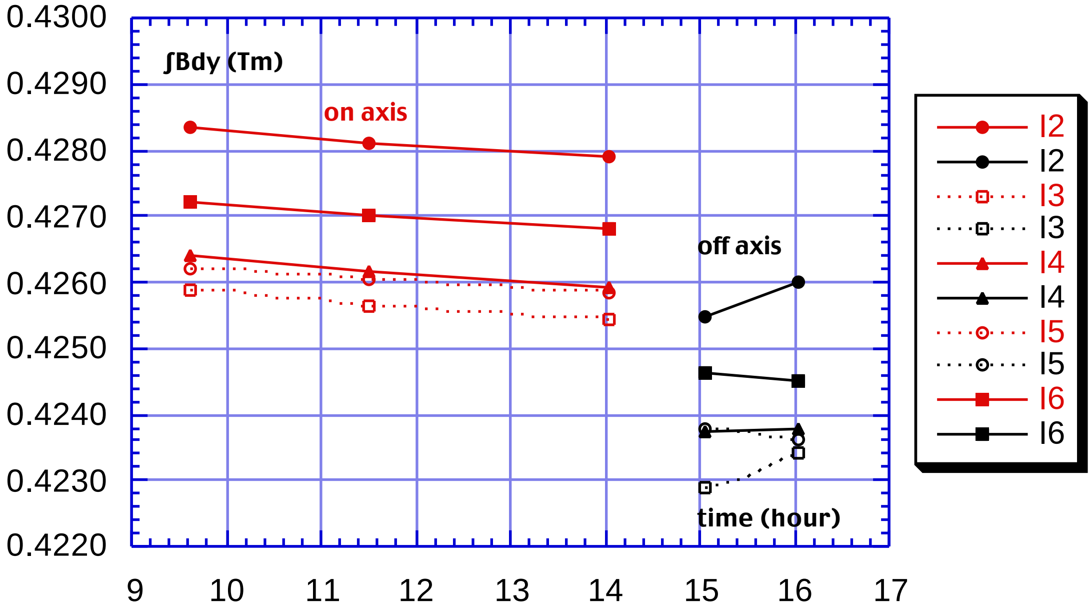


Figure 6 - Field integrals in the central poles (Serial#95989)

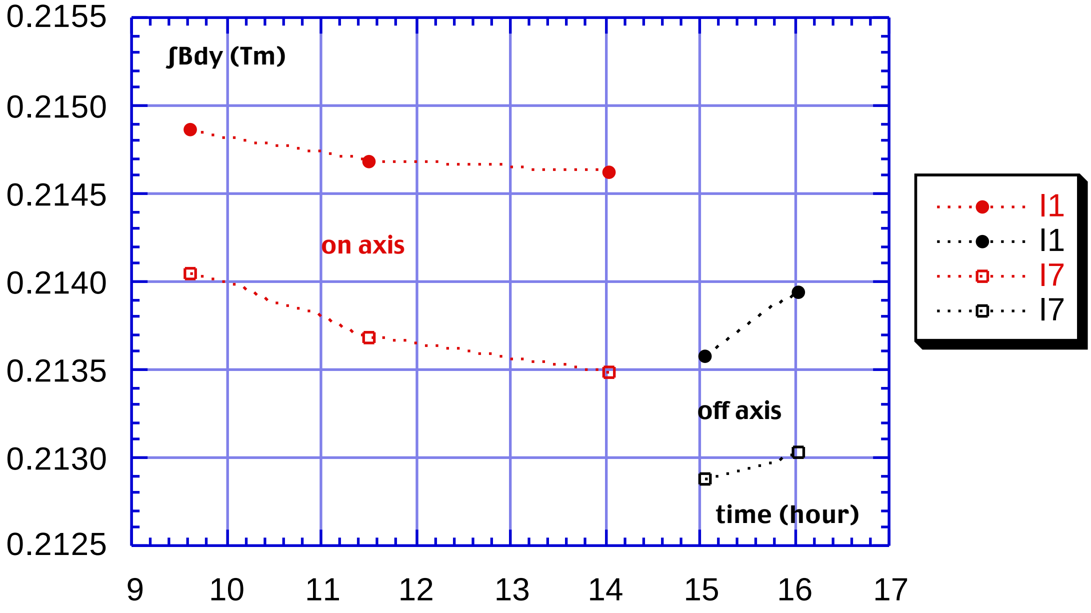


Figure 7 - Field integrals in the terminal poles (Serial#95989)

Let us now concentrate on the terminal poles, although fluctuations of the order of 5 G per pole exist also in the central ones. Figure 8 shows the maximum of the field, Fig. 9 the full width at half maximum. The difference between the maximum fields is less than 7 G (corresponding to ≈ 1 Gm in the integral if this difference is multiplied by the full width at half maximum) and in addition the two differences tend to compensate each other. The full width at half maximum, on the contrary, is larger in both terminal poles at +20 mm, and the total difference is ≈0.3 mm, which accounts very well for the 4 Gm discrepancy in the overall field integral in the wiggler.

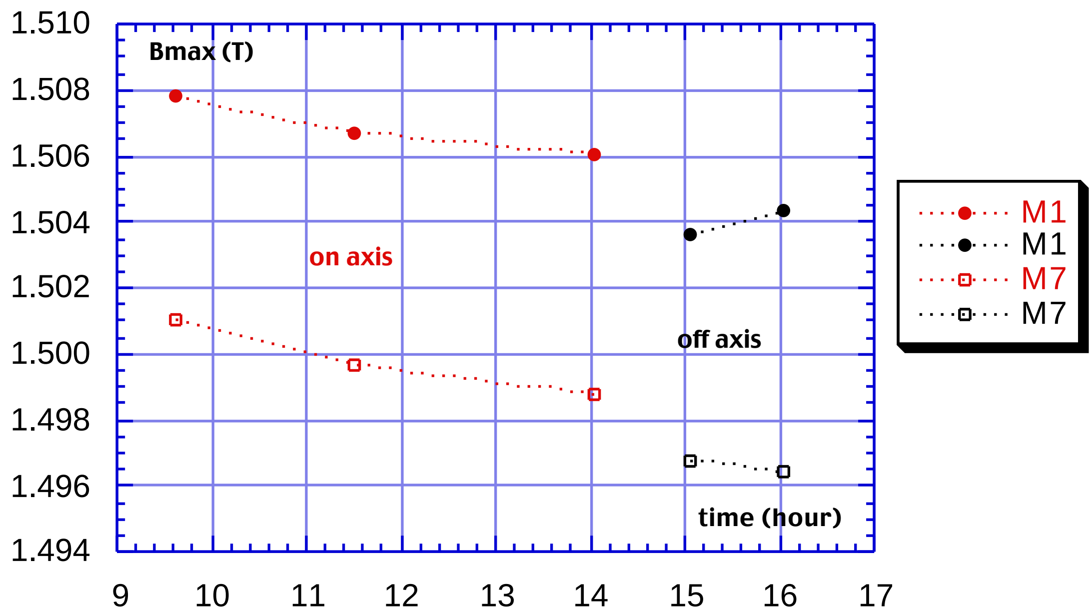


Figure 8 - Maximum field in the terminal poles (Serial#95989)

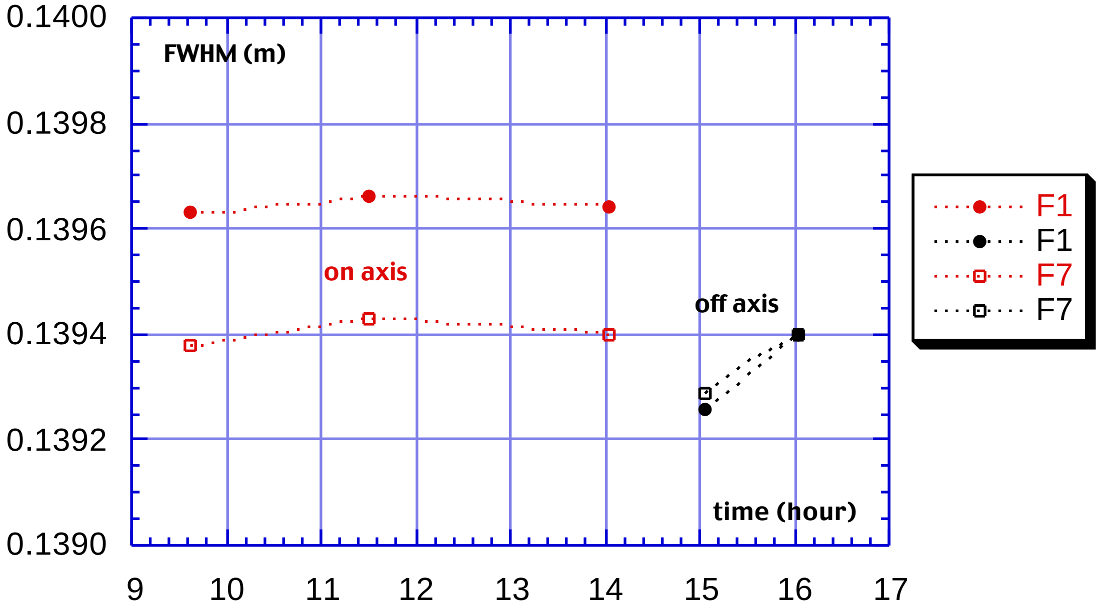


Figure 9 - Full width at half maximum of the terminal poles (Serial#95989)

In order to demonstrate the random behaviour of the difference between the two scans, we show in Fig. 10 the full width at half maximum for the central poles. The fluctuations between the two scans are in both directions and of the order of 0.1÷0.2 mm, which is claimed to be the longitudinal positioning accuracy of the measuring system (see Section 2). Since an error of 0.2 mm in a single pole changes the corresponding integral by ≈4 Gm, we conclude that the system is not able to measure the field integral in single poles below this accuracy.

Taking into account the distribution of the results given in Table I, neglecting the first measurement, and considering the improvement obtained by taking the scan after the thermal conditioning of the wiggler, we conclude that the overall uncertainty on the field integral on axis is of the order of ±5 Gm. However, following the above described procedure, and asking for the consistency of the results from different scans, we can reduce the uncertainty on the field integral by a factor of 2.

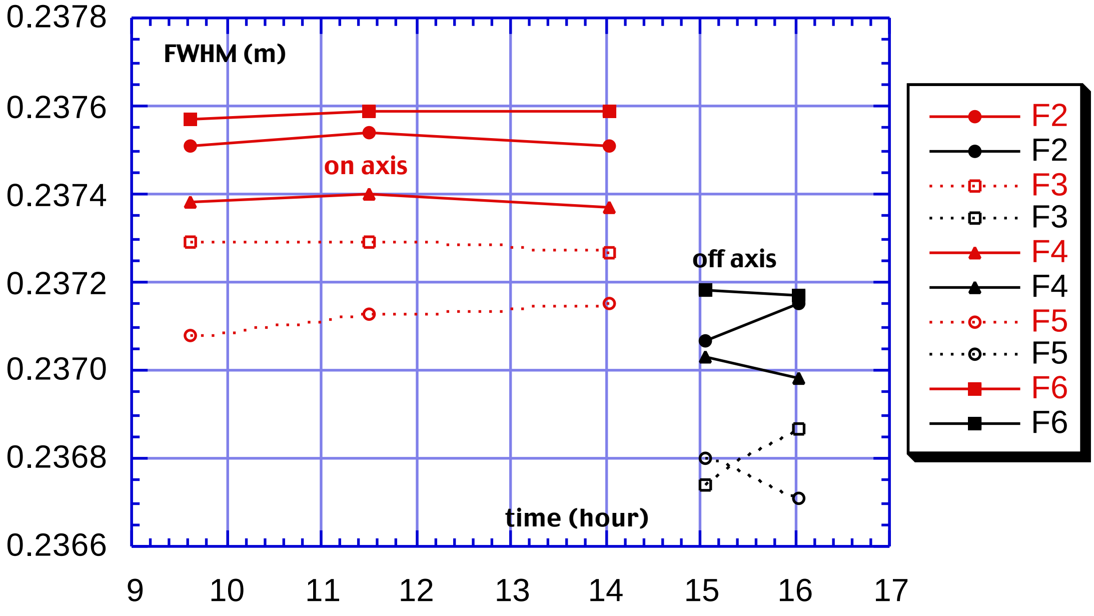


Figure 10 - Full width at half maximum of the central poles (Serial#95989)

The sensitivity of the field integral to changes in the excitation current in the central poles and terminal poles windings has been also measured. Table II summarizes the field integrals measured on the nominal operating point and after changing the currents by 10A. The corresponding derivatives are:

$$\frac{\partial \int B dy}{\partial I_{CP}} = +1.32 \text{ Gm/A}$$

$$\frac{\partial \int B dy}{\partial I_{TP}} = -1.33 \text{ Gm/A}$$

to be compared to the value found on the prototype in 1994 for the second of the two derivatives of -1.44 Gm/A [1].

Table II - Sensitivity of the field integral on wiggler axis to changes of excitation in the two windings

ICP	ITP	∫Bdy
711.9	562.0	+11.03
722.0	562.0	+26.97
711.9	562.0	+9.58
711.9	572.0	-3.72

4. Magnetic measurements on the series production magnets

Table III summarizes the values of the field integrals measured with the procedure described in Section 3 for all the 8 wigglers of the DAΦNE Main Rings. The three numbers in italics correspond to measurements which depart significantly from the smooth behaviour observed in the other ones. The case of Serial#95989 at +20 mm from the axis has already been discussed in Section 3. In order to justify the rejection of the other two we show in Fig. 11 the values of D1÷D5 for Serial# 95993, where D4 is much lower than the others on the third scan, and in Fig. 12 those of F2÷F6 for Serial #95995 where the full width at half maximum F6 is much larger than the others in the first scan. The sign of the discrepancy is in agreement with the wrong values indicated in Table III.

The numbers in bold characters are out best estimate for the field integral in each wiggler with 711.9A in the central poles and 562.0A in the terminal ones. Seven of them are those found in the third measurement when the wiggler has almost reached the thermal equilibrium with the environment of the magnetic measurement hall (temperature controlled at 23 °C). We have chosen the first measured value for Serial#95993, where the third measurement was wrong, because with this choice the field integral at ±20 mm in all the wigglers (except one of the measurements in the prototype) is ≈6 G lower than on axis, in agreement with the result found on the prototype in 1994 [1].

Table IV shows finally our best estimate for the current in the terminal poles winding for each wiggler to obtain a vanishing field integral on the symmetry axis of the magnet. This current is calculated from the bold numbers in Table III with a sensitivity of the field integral to the current in the terminal poles of -1.38 Gm/A, obtained as an average between the results found in 1994 and 1996.

Table III - Field integral values for the 8 wigglers

Serial #	x=0 #1	x=0 #2	x=0 #3	x=+20mm	x=-20mm
95989	9.94	12.20	**12.33**	*2.82*	6.77
95990	24.13	26.66	**29.04**	23.14	23.07
95991	24.35	27.35	**24.47**	18.23	20.48
95992	8.84	7.37	**6.36**	-1.16	0.70
95993	**12.46**	9.88	*15.98*	5.50	6.05
95994	-2.92	-5.13	**-6.50**	-11.46	-11.08
95995	*28.18*	18.76	**17.97**	12.68	12.40
95996	11.90	13.64	**13.87**	7.93	8.55

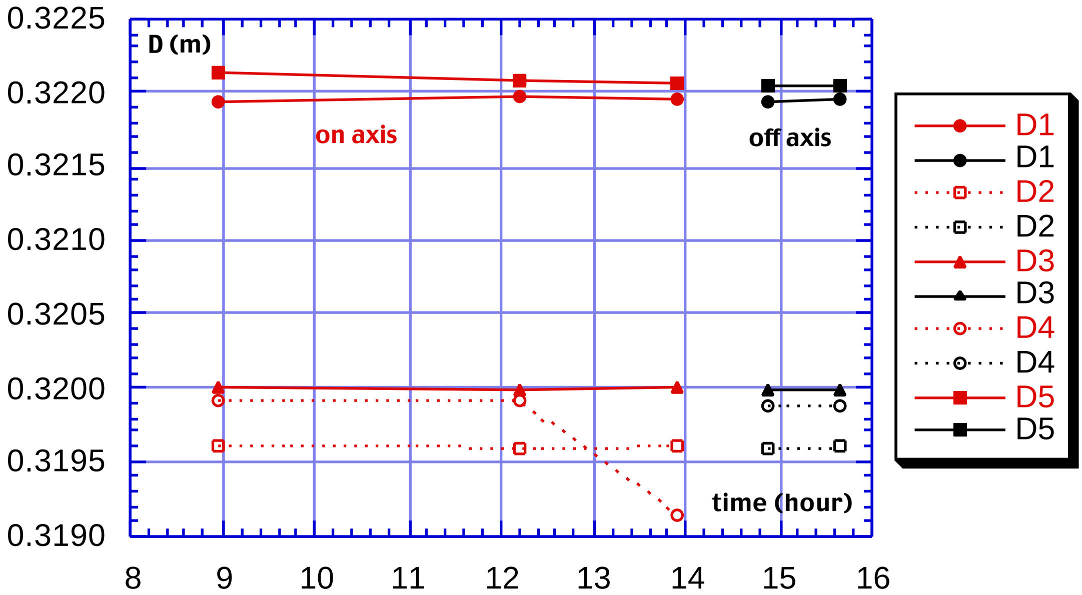


Figure 11 - Distance between points with zero field (Serial#95993)

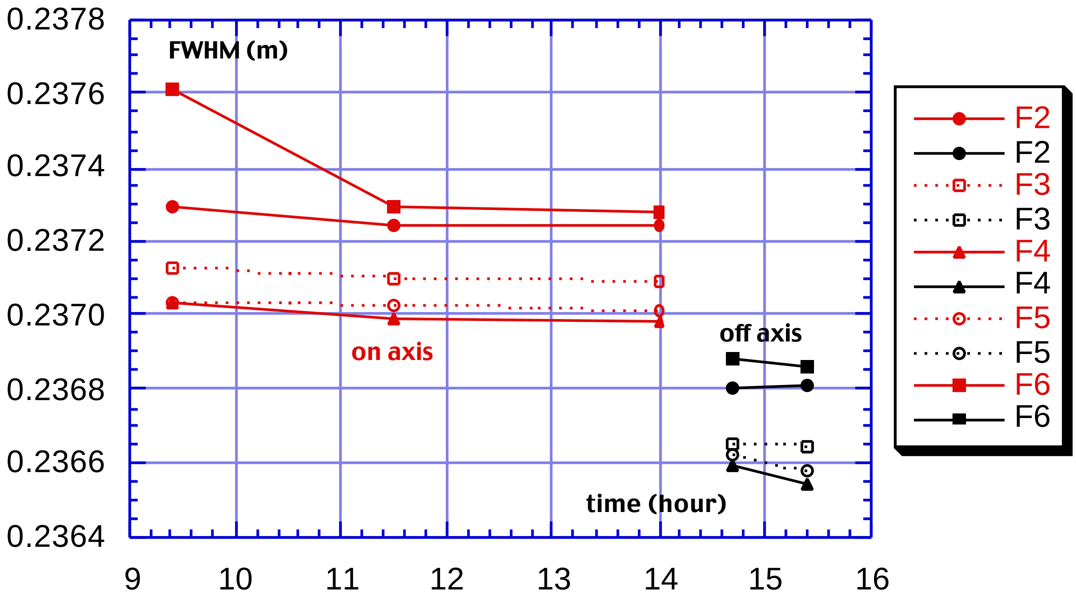


Figure 10 - Full width at half maximum of the central poles (Serial#95995)

As demonstrated in [2], the field integral on the wiggler axis is generally not equal to the field integral on the trajectory followed by the beam, due to the non vanishing sextupole term in the wiggler. However, it has been found [2] that if the beam trajectory starts at an horizontal distance of 14.5 mm from the wiggler axis with the currents set for vanishing field integral on the symmetry axis, the field integral on the beam trajectory vanishes as well. Being this distance approximately half of the overall amplitude of the beam oscillation inside the wiggler, it is an advantage to displace the wiggler axis by the same amount, because in this case the beam trajectory is better centered around the wiggler axis. Under the reasonable assumption that the sextupole term, which depends only on the wiggler geometry, is the same for all wigglers, the values of the terminal poles current in Table IV are the right ones to avoid contributions to the closed orbit from the wigglers.

Table IV - Excitation current in the terminal poles winding
for vanishing field integral on wiggler axis (I_{CP} = 711.9A)

Serial #	I_{TP}
95989	570.9
95990	582.0
95991	579.7
95992	566.6
95993	571.0
95994	557.3
95995	575.0
95996	572.0

5. Conclusions

In spite of some difficulties with the measuring system, a satisfactory set of results for the compensation of the 8 wigglers in the DAΦNE Main Rings achromats has been found at the nominal operating point of the collider. The measurements performed on the prototype in 1994, including the determination of the integrated sextupole component [1], have been substantially confirmed. The uncertainty on the compensation is equivalent to an angular deflection per wiggler of less than ±0.2 mrad.

A dependence of the field integral compensation on the temperature of the magnet has been clearly demonstrated by the measurements. The solid yoke of the magnets requires a rather long time before reaching its thermal equilibrium with the environment: it will be important for a reliable operation to run the collider in a steady state, without switching on and off the wigglers frequently.

Finally, although the above mentioned uncertainty in the compensation has a rather small effect per wiggler, nevertheless the combined effect of four wigglers per ring could be harmful to the overall closed orbit. The final strategy to achieve a fine compensation will be definitely established during the collider commissioning. Here we point out only that finding a working point with the wigglers off could be a powerful solution of the problem, because each wiggler could be accurately compensated at any current by controlling its effect on the closed orbit of the stored beam. As an alternative, the single pass option of the beam position monitors could be used at injection by controlling the beam position before and after each wiggler.

References

[1] B. Bolli, F. Iungo, M. Modena, M. Preger, C. Sanelli, F. Sgamma, S. Vescovi "Measurements on the wiggler magnet for the DAΦNE Main Rings" - DAΦNE Technical Note M-4 (28/4/1994).

[2] M. Bassetti, C. Biscari, M. Preger "Optical characteristics of the DAΦNE wiggler" - DAΦNE Technical Note G-27 (20/9/1994).