Design, Manufacturing and First Measurements of a Hybrid Permanent Magnet Undulator for Free Electron Laser

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Abstract

The hybrid permanent magnet undulator for the LISA-FEL experiment (INFN, Frascati, Italy) [1] has been designed and manufactured under a collaboration between Ansaldo Ricerche and ENEA (Fig. 1). A computerized driving system has been developed in order to ligthen the mechanical structure and gain accuracy in positioning of the jaws during gap variation. The NdFeB permanent magnet blocks have been measured and sorted in order to reduce magnetic field errors along the undulator axis. The field integrals are minimized by the electronic control which feeds the correction coils with a gap dependent current.The first results of mechanical tests and magnetic field measurements confirm the good performances and reliability of the device.

I. INTRODUCTION

The requirements on the field quality of permanent magnet undulators for Synchrotron Radiation Sources and Free Electron Lasers can be satisfied by performing a precise magnetic and dimensional characterization and sorting of the magnetic elements (permanent magnets and poles). It is also important to have a mechanical structure which can accurately position the jaws carrying the magnetic arrays at each gap. The tolerance for the jaws positioning compatible with the magnetic specifications is typically 0.01 mm. A purely mechanical approach in the design of the carriage leads to the manufacturing of components with very high dimensional tolerances. The stiffness must be high enough to keep displacements due to elastic deformations below 0.01 mm at the maximum value of the attractive magnetic force (minimum gap). Systems to control the clearances of the driving system must be foreseen. This solution is expensive and the device is very heavy. A different approach, based on an electronic system which actively controls the parallelism between the jaws during gap variations, has been developed. This system gives a high positioning accuracy of the jaws in spite of a light mechanical structure and a reduction in manufacturing tolerances of the driving components.

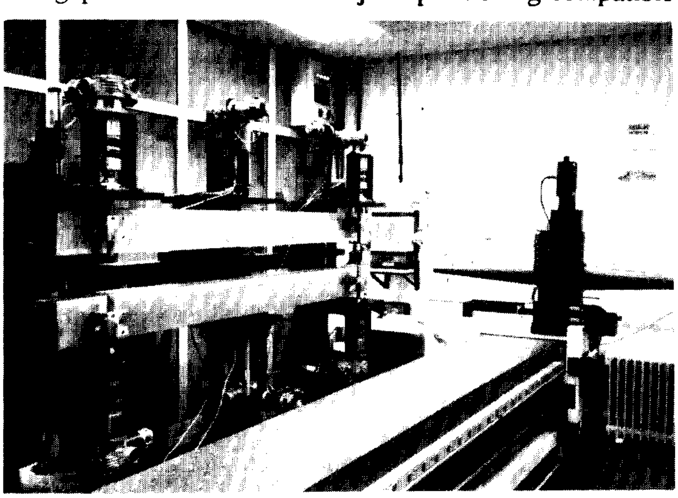

Fig. 1 - Hybrid undulator ON1 and positioning device.

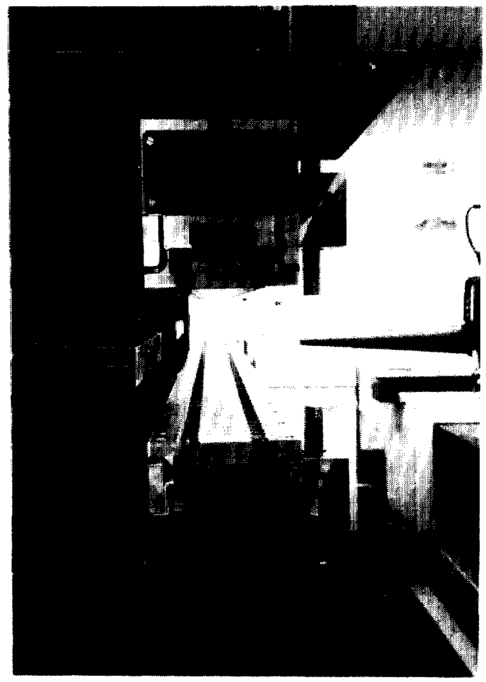

Fig. 2 - ON1 magnetic arrays.

II. DRIVING SYSTEM DESIGN

An innovative design of the mechanical structure and electronic control system for a permanent magnet undulator have been developed in order to have an high accuracy in positioning of the jaws with a simplified mechanical structure [2]. The amount of structural material is minimized and the manufacturing tolerances for the driving components could be relaxed where ever possible so that the weigth and the cost are reduced. Each jaw can be independently displaced by means of three supporting screws which constrain

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the jaws isostatically. Any rotation of screws is converted into a rigid body motion. This allows a complete freedom in the positioning of the jaws so that the parallelism between the magnetic arrays can always be restored. The current position of each jaw is acquired from three linear optical encoders having a resolution of 0.005 mm and sent to the electronic control system. The electronic system is based on a PLC (Programmable Logic Controller) which controls the motors

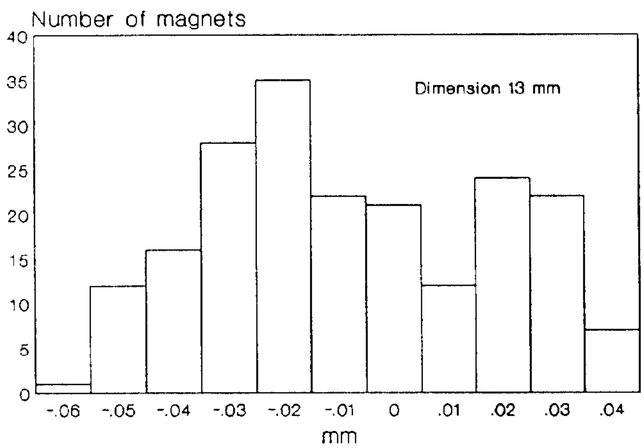

Fig. 3 - Deviation from the nominal dimension (200 magnets).

connected to the supporting screws. This system compensates for the mechanical clearances and small deformations of the mechanical structure arising from the attractive force between the jaws. This active electronic control allows to keep the parallelism between the magnetic arrays during gap variations within the resolution of the optical encoders by means of a PID control of the axis velocities. The system provides also the correction currents, according to the actual gap, during the motion of the jaws.

III. PERMANENT MAGNETS AND POLES ASSEMBLY

The undulator megnetic array has the following main features:

Number of periods	50
Period length	44 mm
Magnets (NdFeB)	13 x 30 x 60 mm
Poles	9 x 26 x 50 mm

The dipole moment of each permanent magnet block has been measured by means of an equipment developed at Ansaldo Ricerche and sorted in order to compensate for the differences in magnetization [3].Each period is assembled by keeping together magnet blocks and poles in an aluminium alloy (ERGAL) holder which is then inserted in to the jaw with a dovetail coupling. The dimensional tolerances of permanent magnets and poles can produce cumulative errors which must be minimized in order to prevent misalignment of the corresponding lower and upper poles. Then both permanent magnets and poles have been measured and the dimensional tolerances have been compensated by means a proper sorting of the poles and exchanging magnets with similar dipole moment in such a way to maintain the average period length. The correct phasing of upper and lower magnetic arrays is verified during assembly by means of a positioning device (Figs. 1 and 2). Figs. 3 and 4 show the results of the dimensional measurements on magnets and poles.

IV. CHARACTERIZATION OF THE PERMANENT MAGNETS

Permanent magnets usually show differences of magnetization which can significantly modify the shape of the magnetic field along the undulator axis. Hence, it is very important to measure these differences of magnetization with high precision and then properly arrange the magnets in the undulator. The equipment set up at Ansaldo Ricerche allows to measure the angular deviation ϑ of the magnetic dipole $\mathbf{m}$ from the nominal direction and the strength ε relative to a reference magnet with magnetic dipole $\mathbf{m}_r$ [3]:

$$\varepsilon = \frac{|\mathbf{m}_r| - |\mathbf{m}|}{|\mathbf{m}_r|}$$

The results of the measurements on NdFeB permanent magnets are shown in Figs. 5 and 6. The sorting software determines the arrangment of the magnets looking for the best compensation of the measured magnetization differences.

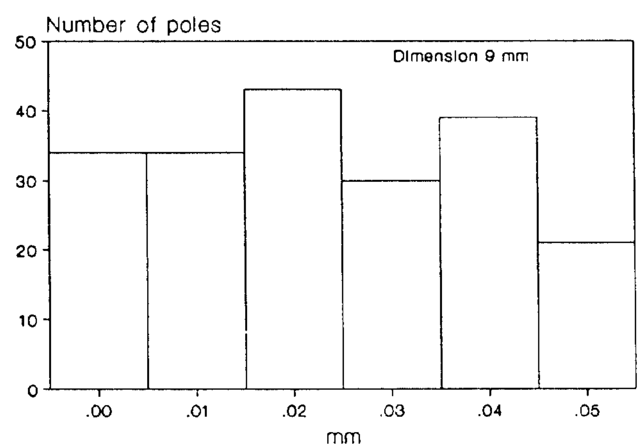

Fig. 4 - Deviation from the nominal dimension (201 poles).

V. MECHANICAL MEASUREMENTS ON THE JAWS

The deformation of the jaws due to magnetic forces at the minimum gap is the most critical parameter in the design of than 0.01 mm. The final mechanical measurements on the undulator have confirmed the FEM calculations.

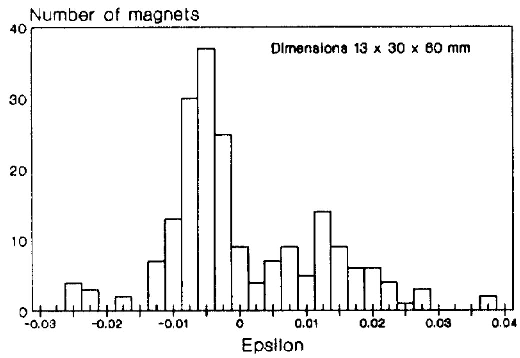

Fig. 5 - Measurements of strength on 200 magnets.

VI. FIRST MAGNETIC MEASUREMENTS

A sistematic campaign of magnetic measurements has been started on ON1 ondulator. A F.W.Bell Gaussmeter (mod. 9900) is used with the Hall probe (mod. HTR 99-0608) mounted on a high precision positioning device ($1\mu m$ positioning resolution). A first scan along the mechanical axis is presented in Fig. 7 with a spacing step of 2.1mm. The measurement has been carried out also using a finer step. The results of these measurements for the central region and the end one, are presented in Fig. 8-9. From these data we have evaluated a rms variation in field amplitude of 0.3%.

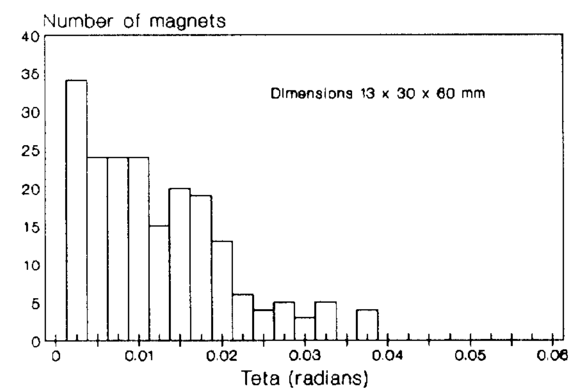

Fig. 6 - Measurements of angular deviation on 200 magnets.

VII. REFERENCES

[1] M. Castellano et al., "The LISA Project in FRASCATI INFN Laboratories" 11th FEL Conference, Naples, Florida, August 28 - September 1, 1989.

[2] F. Rosatelli, F. Ciocci et al., "Advanced Concept in Mechanical Design and Computerized Control System for a Hybrid Permanent Magnet Undulator" 12th FEL Conference, Paris, France, September 17-21, 1990.

[3] F. Rosatelli, F. Ciocci et al., "Development of a Hybrid Permanent Magnet Undulator Prototype for Free Electron Lasers" 11th FEL Conference, Naples, Florida, August 28 - September 1, 1989.

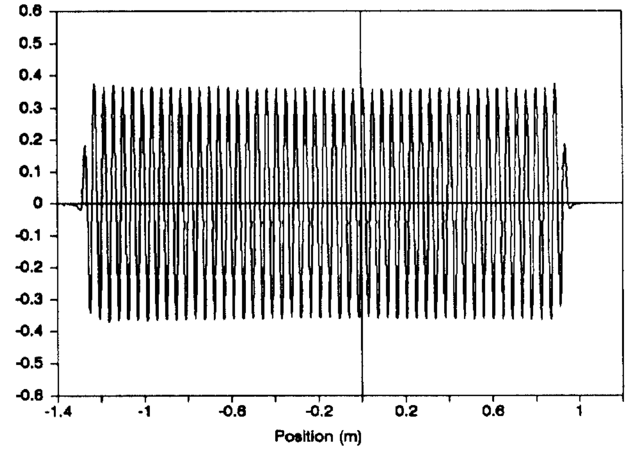

Fig. 7 - Measurements of B (T) along the mechanical axis.

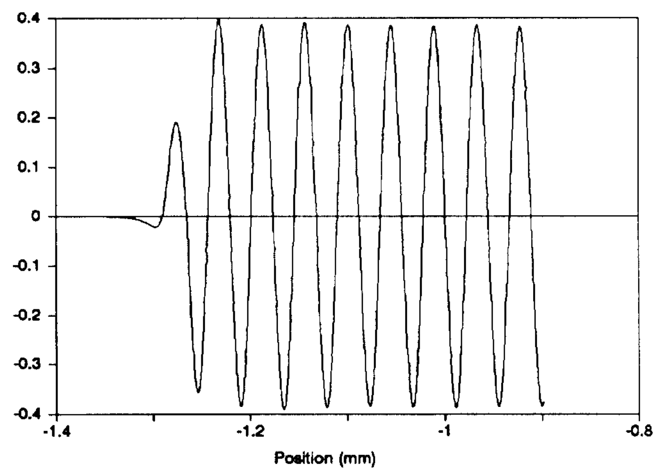

Fig. 8 - Fine measurement of B(T) near the end (mech. axis).

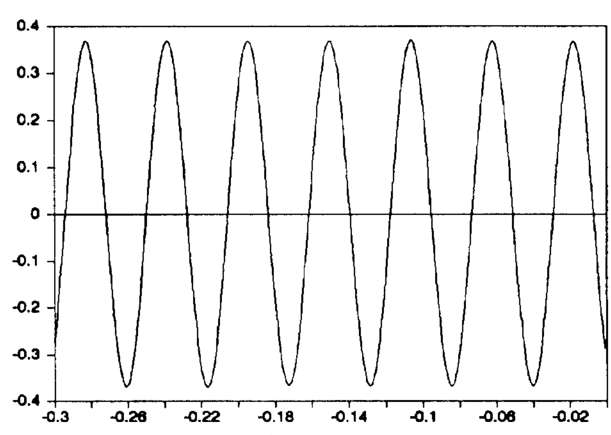

Fig. 9 - Fine measurement of B(T) at the center (mech.axis).