MECHANICAL DESIGN OF THE ELETTRA INSERTION DEVICES AND VACUUM CHAMBER

C. Poloni and R.P. Walker
Sincrotrone Trieste
Padriciano 99
34012 Trieste, Italy

Abstract

The mechanical design of the standard support structure for the ELETTRA insertion devices is described. The results of a finite element analysis to evaluate the effect of magnetic forces and thermal gradients is presented. The detailed design of the 4.8 m long insertion device vacuum chamber and the distributed pumping system is also described.

Introduction

The ELETTRA storage ring [1] will incorporate 12 long straight sections, in 11 of which can be installed insertion devices, undulator and wigglers, up to 4.8 m long [2]. In order to allow the highest flexibility it has been decided to standardize as much as possible the components of each straight section. Following this concept a standard carriage structure 1.5 m long and a standard insertion device vacuum chamber have been designed. Each straight section could be therefore composed of a maximum of three magnet sections hosting magnet arrays of suitable length.

The Insertion Device Carriage

In fig.1 a plan view of the layout of a straight section is shown. The carriage structure is of a C shape to allow an easy installation and replacement from the internal side of the ring without removing the vacuum chamber.

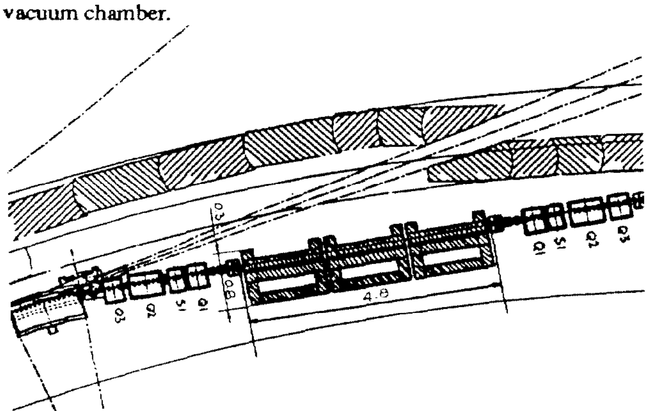

Fig. 1 Plan view of the straight section inside the storage ring

The carriage will have to host any magnetic array foreseen for ELETTRA which led to the following specified performance :

- gap between the reference surfaces 0 - 600 mm
- absolute gap setting (including reproducibility) $\pm 10 \mu m$
- maximum displacement between gap center and nominal electron beam axis (at constant temperature and 0-10 kN of attraction force) $\pm 20 \mu m$
- parallelism between the two reference surfaces $\pm 30 \mu m$
- maximum load due to magnetic force 80 kN
- minimum gap variation step $5 \mu m$

Structure

The main structure is made of a closed rectangular frame supported by a baseframe and two support beams as shown in fig.2. Each I-beam is supported by two ball-screws and guided by two linear bearings; the two rails are mounted on the front face of the frame structure as close as possible to the I-beams. Stainless steel and aluminium were considered for the construction of the I-beams but because of the high cost and unacceptable deformation due to differential thermal expansion in the case of a mixed steel/aluminium structure it was decided to make the whole structure of standard construction steel. A dove-tail allows the clamping of the magnetic arrays on the I-beams for easy assembly and alignment; the same scheme has been adopted for the ESRF insertion devices [3]. For the U2 undulator [4] at 20 mm gap the total magnetic force is 9200 N which with standard IPB200 beams causes a maximum gap variation of $\pm$ 1.1 μm. For the maximum load case, which corresponds to a wiggler magnet, this value is increased to $\pm$ 9.5 μm, but in this case the requirements are less stringent and therefore acceptable.

A finite element stress analysis of the complete structure has been performed in order to verify the performance of the structure with variable magnetic loads and ambient temperature, including the self weight. No relevant stress exists in the structure and only deformations had to be verified. The results have shown that the most critical parameter is the vertical position of the gap center since changes in the gap that also occur are detected by the encoder system. For the vertical position of the gap axis a displacement of -3.2 μm / kN and 8.0 μm / °C can occur. To reduce the effect of this error during operation the alignment of the undulator will be carried out at the minimum gap. It must be noted that the temperature inside the ring will be within 25-30 °C and no large variation in temperature is expected between adjacent sections. The displacements of the I-beams in the horizontal plane stay within $\pm$ 50 μm even with a temperature change of 10 °C and rotation around all axis are negligible (< 0.08 mrad with 9.2 kN, < 0.46 mrad with 80 kN).

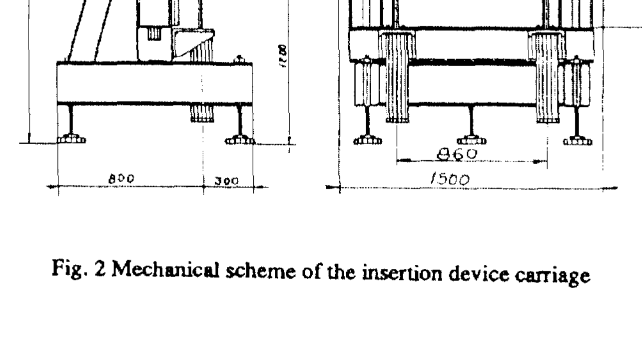

Fig. 2 Mechanical scheme of the insertion device carriage

Figure 2 shows the preliminary design of the carriage developed by Sincrotrone Trieste. The prototype being constructed by CONTEK S.p.A. in Varallo, Italy, differs somewhat from this design; the use of Belville springs to compensate the magnetic force has been abandoned in order to avoid possible sticking problems during long time operation. Moreover any carriage will be compatible with any magnetic structure as there is no longer the need to change the spring set.

Driving System

Two solutions have been evaluated for the driving system. The first one using two screws with opposite threads, the second using four independent screws. For the prototype the second solution has been adopted, even if more complicated from the control point of view, for the following reasons:

- each driving group composed of screw, gear reducer, dc motor and magnetic brake is an industrial component
- the position accuracy is determined by the optical encoders so any possible loss of accuracy due to wear of mechanical components can be avoided as the encoder, positioned very close to the gap, can read the real position of the I-beams
- the symmetry axis of the magnetic structure can be adjusted via software allowing a more accurate alignment in the vertical direction with respect to the electron beam axis.

Each dc motor is capable of a nominal torque of 11 Nm (peak value 70 Nm) and of a maximum turning speed of 2000 turn / s. The worm-wheel reducer has a transmission ratio of 1:40 and the ball screw has a step of 10 mm. With these characteristics the translation speed foreseen for each I-beam during operation will be programmable between 0.28 mm / s and 5 mm / s. Thus the time to open from minimum to maximum gap will be less than 60 seconds. The nominal power required by the whole carriage will be $\leq$ 3 kW. The safety system is composed of software end stop, electric end of run switches and mechanical end stop; a magnetic brake installed on each driving unit is automatically activated in case of power failure or via software if the gap is to remain fixed for a long time. In this case the main power is switched off and only the power required by the control electronics is maintained.

Each carriage is an independent unit with its own on-board electronics capable of a closed loop control of the gap. The communication with the main control system of ELETTRA will be performed by means of macro commands given to the carriage through a RS 232 communication standard.

Insertion Device Vacuum Chamber

For the straight section vacuum chamber the main parameters required together with vacuum requirements, are related to the shape of the cross section which must allow a minimum gap of 20 mm between the magnets with a sufficient vertical beam aperture (15 mm at 2 GeV). The chamber material is also fixed by the general requirements of the ELETTRA vacuum system [1,5] which will be completely made of stainless steel AISI 316 LN.

As for other similar rings [6,7] both lumped and distributed pumping solutions have been investigated. The second solution is preferred since the pressure profile is smoother and the mean value lower for a comparable installed pumping capacity [8].

The cross section adopted for the constructive design of the chamber is the one shown in fig. 3. The straight pipe will be 4.8 m long without any variation in the external thickness as the individual insertion device magnet sections will be located very close to each other. The proposed solution consists of an elliptical pipe obtained by deformation of a commercial circular pipe with 1.5 mm wall thickness with a 4 mm thick welded ante-chamber.

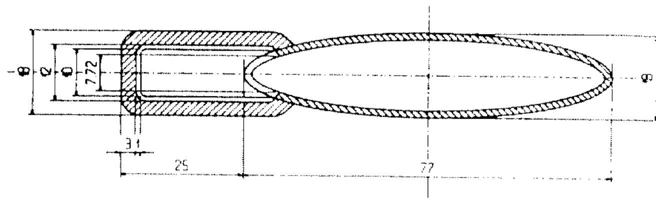

Fig.3 Insertion device vacuum chamber cross section

The pumping port is formed by a series of 25 slots / m having a cross section of 10 x 16 mm. The pumping capacity is given by two NEG strips, 15 mm wide, located in the ante-chamber. To drive the getter during the activation process (getter temperature 450 °C chamber bakeout temperature 150 °C) macor™ or ceramic spacer disks will be installed every 200 mm. The getter will be electrically activated from one side of the chamber where two flanged feed throughs are placed. At the two ends of the straight part two tapered sections 230 mm long connect the ID chamber to the remaining ring and to two ion pumps, fig.4.

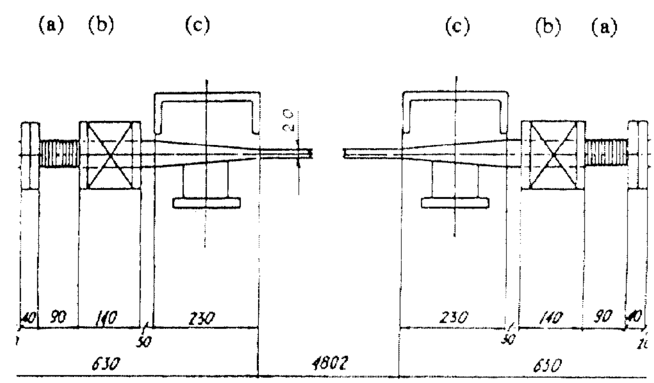

Fig. 4 Schematic view of insertion device straight section, showing (a) bellows, (b) beam position monitor, (c) corrector magnet and pumping port

Structural Calculations

As the space available is small the chamber wall thickness had to be minimized in order to relax the positioning and machining tolerances. The dimension of the pumping slots and the ante-chamber wall thickness had therefore to be considered carefully in order to warranty the needed structural stiffness.

Several ante-chamber cross sections and slot sizes have been investigated [8] using the ABAQUS finite element stress analysis package [9]. The one finally chosen offers the best compromise between the vacuum conductance of the slots and structural needs. For the final shape loaded with the outer pressure and a temperature increment of 150 °C, the non linear analysis performed using large deformation theory, showed a maximum stress of 138 N mm^{-2} while the total external thickness of the chamber is reduced by 0.18 mm. The chamber material yield stress at the bakeout temperature is 197 N mm^{-2} therefore an adequate safety factor of 1.4 is maintained.

From the point of view of thermal loads, since the insertion device vessel starts sufficiently far from the upstream bending magnet (1.2 m), no significant heating of the chamber will occur. Undulator or wiggler radiation will not heat it either as the beam width at the end of a radiation source is always significantly smaller than the vacuum vessel aperture. It had to be verified however that the getter activation at 450 °C does not damage the chamber. It has been shown using a finite element model that the heat radiated by the getter can be dissipated by the chamber and the bakeout temperature maintained if the chamber is equipped with proper heaters and thermal jackets.

Vacuum Calculation

Detailed MonteCarlo method calculations have been made and the complete results are reported in [8]. Considering a nominal pumping probability of 250 l $s^{-1}m^{-1}$ to the NEG installed, the effective pumping that can be seen by the chamber for various slot sizes is summarized in the table 1.

Table 1. Effective pumping speed and maximum stress for various slot sizes.

Slot size $[mm^2]$	No.of Slots $[m^{-1}]$	NEG effective Pumping Speed $[l\ s^{-1}m^{-1}]$	Max. Stress (linear analysis) $[N\ mm^{-2}]$
10x10	50	138.4	-
10x50	10	131.0	-
10x20	25	145.1	182
10x10	25	135.6	127
10x12	25	115.2	110

Starting from a slot size that gives an equal length of pumping aperture and wall length, an optimum was found with approximately 25 slots per meter. After some reduction in the slot size in order to reduce the maximum stress value to an acceptable level, a final arrangement with 10x16 mm slots was arrived at. Assuming a thermal outgassing of 5. 10^{-11} Torr l s^{-1} cm^{-2} for AISI 316 LN, an outgassing due to photon incidence of 2.4 10^{-7} Torr l s^{-1} for a 4.8 m chamber and a more conservative installed pumping speed of 80 l $s^{-1}m^{-1}$ the average pressure calculated is 7.6 10^{-10} Torr in the case of distributed pumping and 2.0 10^{-9} Torr in the case of lumped pumping (one pump every 750 mm, 120x10 mm slot size, 60 l/s pumps).

An estimate of the time interval between two successive getter activations has been made. With a reasonable value of 0.2 l m^{-1} for the gas pumped by the NEG before it reaches a lower limit of 10 l $s^{-1}m^{-1}$ pumping speed we get an estimate of the time interval of 1000 hours of operation for the assumed outgassing rate which is therefore acceptable.

Conclusion

The insertion devices for ELETTRA will have a standard support structure. The results of the stress analysis calculations indicate that acceptable mechanical performance should be achieved. The first prototype carriage has been constructed and the acceptance tests will be carried out by the end of June 1990.

The insertion device vacuum chamber has been designed and a laboratory prototype 2.4 m long will be constructed during the following months to prove the technological feasibility of a full length chamber.

Acknowledgements

This work was made with the collaboration of R.Kersevan and T.Monaci, from Sincrotrone Trieste, for the vacuum calculations and for the constructive design of the chamber. CONTEK S.p.A., Varallo Sesia, Italy, has carried out the detailed design and construction of the carriage prototype.

References

[1] "ELETTRA conceptual design report", Sincrotrone Trieste, Padriciano 99, 34012 Trieste, Italy, April 1989

[2] B.Diviacco and R.P. Walker, this conference

[3] P.Elleaume, Private Comunication

[4] B.Diviacco C.Poloni R.P.Walker, "Conceptual design of an Undulator Radiation Source for a Super-Esca Beamline on ELETTRA", Sincrotrone Trieste Internal Report, ST/M-TN-89/90

[5] R.Kersevan, "Calculation of pressure profiles in the ELETTRA vacuum chamber ", Sincrotrone Trieste Internal Report, ST/M-89/22

[6] B.Tricket, "Pumping undulator straight" ESRF-VAC 88-08

[7] S. Kim, R. Wehrle and L. Genens, "Vacuum chamber for an undulator straight section" Proceedings of the 1987 IEEE Particle Accelerator Conference

[8] R.Kersevan and C.Poloni, "Preliminary design of the insertion device vacuum chamber", Sincrotrone Trieste Internal Report, ST/M-TN-90/2

[9] ABAQUS finite element pakage, Hibbit Karlsson & Sorensen Inc.