THE SPANISH PROJECT FOR A SYNCHROTRON LABORATORY AT BARCELONA (LSB)

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Abstract

In response to the ever increasing demand for access to synchrotron radiation (SR) sources the Spanish funding agency CICYT and the Catalan one CIRIT have jointly commissioned a detailed feasibility study for a national Synchrotron Laboratory at Barcelona (LSB). An analysis of the current and predicted needs has established the following priorities: broad range of utilisation, high beam stability and long lifetime, small vertical and horizontal source dimensions, vertical collimation, horizontal collimation and time structure. The design of the LSB cannot be adventurous because, among other reasons, it must deliver photons from day one to a "photon hungry" community, nevertheless its design must have the potential for substantial further development with which to face the challenges of SR research in the 21st century. The proposed characteristics of the accelerator will be reviewed and put into context in relation to the needs that have to be satisfied.

1 INTRODUCTION

Synchrotron Radiation (SR) emitted by the bending magnets of an electron or positron storage ring, with its well known properties of spectral continuity, intensity, collimation, polarisation and time structure, has been for some time the most versatile source of electromagnetic radiation available. In addition, the radiation delivered by insertion devices such as multipole wigglers and undulators can have a brightness which is several orders of magnitude superior to that delivered by the bending magnets. The quality of SR, whether from bending magnets or from insertion devices, is such that its use is now an essential requirement for cutting-edge fundamental and applied research. Spain has a substantial and growing scientific community who needs access to SR sources. Currently this access is obtained at national sources elsewhere and also at the European Synchrotron Radiation Facility (ESRF) at Grenoble, of which Spain has a 4% share of the costs. The characteristics and scientific brief of the ESRF precludes its usage in the soft X-ray region or at lower energies where many of the needs of the Spanish community are to be found. Moreover, the ESRF at full capacity is expected to provide a total public volume of utilisation of ca. 35 beam line equivalents per year. Included in this number there is the fraction of the so called CRGs (i. e. beam lines built and operated by external collaborating research groups) available to the scientific community at large as well as the public beam lines (built and operated by the ESRF). With a 4% share of the ESRF the Spanish scientific community can only expect a yearly average access of ca. 1.4 beam line equivalents. Leaving aside issues such as whether the facilities at the ESRF map onto the Spanish future needs and the desirability of having regular access to the technological know-how derived from having a national SR source, this volume of access is already insufficient for current needs and precludes the future expansion of the Spanish scientific community involved in research at the forefront of technological possibilities.

Recognising this situation, Spain has decided to invest via the CRG route on its own beam line at the ESRF and it is jointly funding a beamline at Super-ACO (DCI). Alongside these short term solutions there is an agreement between the CICYT (Comisión Interministerial de Ciencia y Tecnología) and the CIRIT (Comissió Interdepartamental de Recerca i Innovació Tecnològica) to fund a detailed design study for a future national SR source. This paper describes the overall goal of this project and its current status.

2 SCIENTIFIC BACKGROUND

Practically all scientific disciplines use photon based techniques. In particular, research in the physical, chemical, biological, materials and applied sciences makes extensive usage of these methods and within this framework there are emerging scientific and technical challenges which can only be met by those who enjoy unimpeded and regular access to synchrotron radiation sources. A few examples of these new challenges are sketched below.

Very often the functionality of materials relates to minor phases. This type of materials range from glasses to self-assembled clusters, from quantum dots to impurities in semiconductors. To determine the properties of these materials the knowledge of their atomic structure and of the atomic environments of the minor phases as the functionality of the material is generated (or lost) is required. To this end one must use non-invasive X-ray spectroscopic and imaging techniques. For example, the microstructure which determines the functionality of most polymer and ceramic products is submicron and multiphase. The limitations of conventional methods restrict probing this structure to *ex situ* measurements and the most that can be achieved in picturing the fundamentals of a manufacturing process is the capture of a series of “stills”. On the other hand SR techniques allow the *in situ* structural differentiation and the elucidation of the phases as they change because the speed of data acquisition matches, in principle at least, that of manufacturing rates. Experiments of this nature might lead to a quantification of what, in many cases, is still an empirical science with many potential industrial returns, e.g. polymer processing technology can incur considerable waste and an improved understanding of the principles would be directly beneficial in reducing wastage. However, for the development of these technologies use and regular access to SR is an absolute requirement.

Many advances are taking place in magnetism and surface engineering. Research in these disciplines is required for the production of sensors and storage devices and relates to problems of “wear and tear” as well as to the alteration of surfaces for particular applications. With regards to surface engineering, for example, it is often the monolayer at the surface or interface that its critical and the chemistry is that of second and third row elements in the periodic table. Probing carbon, oxygen and nitrogen and the orientation of molecular species demands very high photon intensities at soft X-ray energies as well as polarisation. To bring precision and diversity to these methods and feed directly into the knowledge required to understand and improve anti-corrosion coatings, lubricants, electrochemically altered surfaces, hydrophobic coatings, adhesives etc., it is essential to use SR from purpose-built insertion devices operating at soft X-ray energies.

Within the life sciences there are many techniques which are "photon hungry" and thus require SR. For example, using time resolved X-ray diffraction techniques one can study conformational changes of macromolecules in solution, i.e. in their functional environment, their folding, and their self-assembly. The central difference between these SR techniques and more conventional spectroscopic methods is that in addition to kinetic information they provide direct structural information at the molecular level. There are also many biological complexes that naturally form two-dimensional arrays (e. g. membrane systems). Glancing angle X-ray diffraction experiments, similar to those currently performed on inorganic surfaces, could provide direct information about the structural dynamics of these systems when they carry out their function (e. g. transporting ions or small molecules across a membrane). Similar considerations apply to the studies of structural dynamics of many "live" fibrous structures, biological organelles or tissues (e.g. DNA, microtubules and muscle tissues). In all cases the weakness of the scattered/diffracted signals demands the use of SR.

Even with the traditional, and relatively straightforward from a technical point of view, macromolecular crystallography techniques, many limitations due to insufficient photon fluxes can only be solved using SR. In addition, SR is absolutely required for the development of future methodologies. For example, anomalous scattering methods have long held the promise of providing a direct experimental method for solving the phase problem. But the need to have a tuneable X-ray source and the precision required in the measurement of the diffracted intensities requires SR. Cryogenic methods, where important structural intermediates formed during a reaction are frozen, can only be applied effectively to very small crystals and once again the intensity is the limiting factor

Finally, there are a number of emerging techniques, such as magnetic circular dichroism (CD), SR confocal microscopy and correlation experiments using X-ray diffraction/scattering methods which have enormous potential for structural/functional studies in biological systems. All of these methods are at the moment either an idea or no more than a demonstration experiment and will only become routine applications if unimpeded access to SR sources and to purpose built, optimised experimental stations, is available. Currently, the shortage of SR beam time prevents the development of many of these ideas. This problem is particularly severe for the Spanish scientific community because lacking its own national SR facility it can contribute neither to the development of these new methods nor to the exploitation of existing technologies with the same level of expertise that has been developed in nations with their own source. In addition to the industrial and technological benefits derived from the know-how acquired from a national SR facility there is the important strategic aspect of providing a level playing field for Spanish scientists.

3 USER COMMUNITY

Part of the brief of the LSB staff is to define the specifications of a future SR source which are commensurate with current and longer term needs. In practice this means a national SR source with built-in possibilities for expansion. Recently, a national survey was carried out and this was followed by a workshop attended by the future user community. A total of 87 groups wishing to use SR replied to the survey [1]. These are very active groups as, on average, they manage 1.7 projects per year, They also cover a broad range of disciplines including Materials Science (35%), Molecular Sciences (23%), Surface Sciences and

Interfaces (18%), Structural Biology (10%), Chemistry (5%), the study of industrial processes (4%), Atomic and Molecular Physics (3%) and instrumentation (2%). About 75% of these groups expressed the view that they required access to spectroscopic and diffraction methods using X-rays, with a majority (70%) requiring X-rays of intermediate energies (4-20 keV). The remainder of the replies indicated a requirement for optimised radiation at longer wavelengths such as it can be provided by tuneable undulators. To satisfy these requirements it is necessary to construct an accelerator that provides a measure of overlap with the spectral range provided by the ESRF and which can accommodate insertion devices such as multipole wigglers, superconducting wigglers and undulators.

4 SOURCE SPECIFICATIONS

A source with which to cover these needs must have a minimum particle energy of 2.5 GeV and, indeed, this is the design energy of the proposed machine. Very high brightness X-ray beams are not perceived as being the main objective of such source, on the other hand a broad range of utilisation, stability, long lifetimes, small source size and high fluxes are seen as very important requirements. To achieve this specification the current design is based on a TBA lattice, consisting of 12 cells and incorporating straight sections with free lengths of up to 7.3 m. The essential reason for choosing a TBA lattice is that it offers a good compromise between low emittance (specially small source sizes), relatively comfortable tolerance to magnetic imperfections, large dynamic aperture and good potential for low emittance coupling (at the moment conservatively estimated at 5%). Further details about the design specifications and list of relevant parameters are given in Table 1 of ref. [2].

In the current design the magnetic lattice consists of 36 combined magnets without a central field strength of 1 T and a gradient of 3.3 T/m. The lattice also includes 3 families of quadrupoles and 3 families of sextupoles [3]. It should be noted that the bending magnets are far from saturation and, therefore, there exists the possibility for ramping to higher energies if the scientific case ever demands it. Also, the possibility exists for the replacement of one or more pairs of central dipoles in some of the TBA cells by short superconducting magnets giving much higher energy photons if and when required. In the long term it might become desirable to provide beams with high brightness in the region of intermediate energy X-rays. The combination of narrow gap undulators and the use of high orders from undulators with appropriate shimming offers such prospect. Therefore, injection will be at nominal energy so that the expected lifetime reduction associated with the use of narrow gap undulators can be compensated for.

With regards injection, the main requirement is that the LSB should enjoy good injection efficiency. To this end a booster synchrotron with relatively low emittance, beam size at the extraction point and an adequate harmonic number will be needed. A booster synchrotron with a FODO lattice, operating at a maximum energy of 2.5 GeV and with a circumference of 126 m appears to fulfil the desired specifications [4]. Injection into the booster from a 0.1 GeV pre-injector (as yet not fully defined) can be done with a septum and kicker combination. Injection from the booster into the storage ring is complicated because of space considerations and the relatively high energy of injection. A modified version of the scheme proposed by S. Tazzari for the ESRF [5], i. e. using two septum magnets in tandem, appears to solve the problem and yields good injection efficiencies [6]. Details of the current designs of the pulsed magnets for injection and extraction are given in ref. [7].

The LSB will have the capacity to incorporate up to 10 insertion devices. At this stage only relatively straightforward undulators and multipole wigglers (MPW) are being considered as they appear to satisfy the requirements of known future users [8]. The study of the non-linear behaviour of particles has shown that a comfortable dynamic aperture is possible with the current design of the LSB and with the chosen working point [9]. The effect on the dynamic aperture due to the introduction of undulators is essentially negligible. However, the introduction of MPW, specially for high on axis magnetic fields, has a non-negligible effect on the dynamic aperture which is practically halved. Even though compensation for the tune shift and chromaticity leads to the recovery of a large enough horizontal dynamic aperture and the vertical dynamic aperture is acceptable, this is an area where further study will be needed.

Vacuum, RF and control systems are essential components in determining the good behaviour of any accelerator. Evaluation of the vacuum requirements is in progress. It appears that either a rectangular or elliptically shaped vacuum pipe with minimal dimensions of ca. 50×20 mm^2 would be acceptable from the point of view of the accelerator design (e.g. Touschek effect). Nevertheless, these dimensions would yield relatively small vacuum conductances and in practice the vacuum pipes in the straight sections will be significantly larger, at least in the horizontal plane. The very compact magnetic lattice of the TBA cell imposes limitations in the positioning of the vacuum components at the ideal points. Modelling studies [10, 11] have shown that an acceptable mean pressure can be achieved during beam on conditions. Nevertheless, these studies show that the vacuum pressure will rise to relatively high values in the regions where radiation from the bending magnets hits components. Thus, and even though no detailed design has yet been carried out, it appears it might be necessary to introduce distributed ion pump strips into the design of the dipole vessels.

With regards to the RF system, the frequency has been chosen to be 500 MHz and four Bell shaped cavities will be used. The choice of Bell shaped cavities is largely determined by the requirement to achieve temperature control within 0.2°C in order to avoid multibunch beam instabilities. A total power of 1.2 MW will be installed. This should secure: a) comfortable operation with 250 mA circulating currents; b) the option to achieve this current with a 50% gap in the fill to allow the clearing of ions and; c) a reasonable bunch length (ca. 20 ps) in single bunch operation [12].

With regards to the control system it is proposed to adopt the so called "standard model" [13]. Although much work remains to be done in this area of the design, it is clear that the requirements point to the use of a distributed system with a three-level hardware architecture (high level processors with global control functions, medium level processors with functional control functions in real time and low level processors controlling the I/O of the equipment). Exploitation of the growth in commercially available hardware (VME/VXI products) and software is intended.

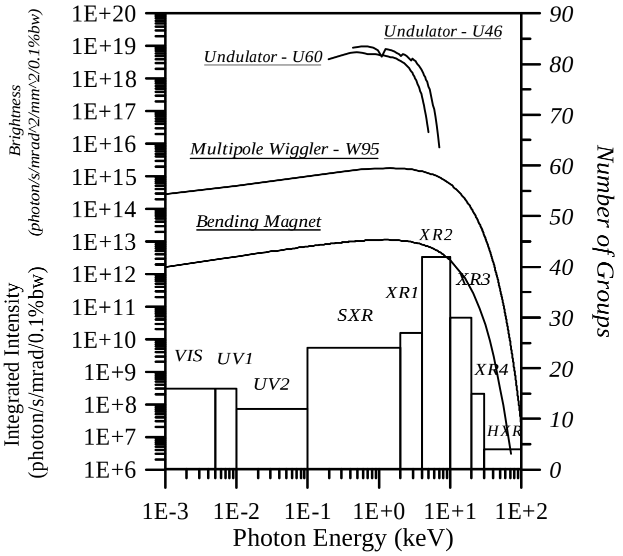

Figure 1: Integrated Intensity for photon emission from bending magnets and a typical MPW, and Brightness from typical undulators. For further details see ref. [8]. The figure also shows the distribution in terms of energy ranges and number of groups for the current Spanish SR user community.

Finally, the expected performance from a user point of view, i. e. in term of integrated intensities in a wavelength bandwidth of 10^{-3} and brightness for the bending magnets and from a number of insertion devices is given in Fig. 1. This figure also shows how the range of utilisation maps onto the current requirements. Table 1 gives a number of user parameters for bending magnets, undulators and MPW such as horizontal (σ_x) and vertical (σ_y), source dimensions and divergences (σ'_x, σ'_y). The divergences are given at the critical photon energy where appropriate (bending magnet and MPW). The dimensions for the undulator are those corresponding to emission in the central cone.

Table 1: Source Parameters

Energy	2.5	GeV
Number of Cells	12	
Free straight section length	7.2	m
Straight section for Ids	10	
Critical energy	4.2	keV
σ_x (bending magnet)	ca. 160	µm
σ_y (bending magnet)	ca. 80	µm
σ'_y (bending magnet)	ca. 130	µrad
σ_x (undulator)	ca. 350	µm
σ_y (undulator)	ca. 40	µm
σ'_x (undulator)	ca. 30	µrad
σ'_y (undulator)	ca. 20	µrad
σ_x (MPW)	ca. 370	µm
σ_y (MPW)	ca. 40	µm
σ'_y (MPW)	ca. 160	µrad
Horizontal Emittance	7.85	nm-rad
Vertical Emittance	0.50	nm-rad

An expanded view of the storage ring cell, showing the position of critical magnetic elements is shown in Figure 1 of ref. [2].

5 CURRENT STATUS AND FUTURE PLANS

The conceptual design and much of the detailed specifications of the LSB is reasonable advanced. A laboratory for the testing and development of magnetic structures is currently being constructed. Also, construction of prototypes of crucial elements, e. g. bending magnets with gradients, is now in progress. Following a nation wide survey, the first formal meeting of the future LSB users took place in December 1995. The aim of this meeting was to specify the characteristics of the first ten beamlines, which are included in the brief of this detailed feasibility study. The detailing of these beam lines has now begun. The intention is to have a complete and costed proposal by the end of 1997 which will then be submitted to the relevant funding bodies. Thereafter, these bodies will have to consider budget approval for the construction phase and appropriate spend profile. It is expected that the time scale for construction and commissioning will be ca. 6 years from the moment of budgetary approval.

In the meantime, further studies will be carried out regarding the behaviour of the accelerator when some of the conceivable expansions are included. For example: the effects of ramping to higher energy and the influence of superconducting dipoles on the beam brightness; the deterioration in the lifetime due to inclusion of narrow gap undulators, and; the possibility of a further reduction of the source dimensions by inclusion of pairs of quadropoles in symmetrically disposed straight sections.

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