THE ECONOMIC OPTIMISATION OF THE MAIN PARAMETERS OF THE 3 GEV ELECTRON BOOSTER SYNCHROTRON FOR DIAMOND

N. Marks, D. M. Dykes, S. A. Griffiths, D. J. Holder, J. Kay, R. J. Reid,
R. Ryder, S. L. Smith, B. Todd, CLRC Daresbury Laboratory, Warrington, U. K.

Abstract

Usually, the boosters for synchrotron light sources and other storage rings are physically smaller than the storage ring, with higher dipole fields. However, the Swiss Light Source, (SLS) [1] incorporates a full-energy booster, with a circumference approximately equal to that of the storage ring. In the preliminary design work for the proposed UK 3 GeV synchrotron source, DIAMOND, the optimum size and number of cells in the full-energy booster synchrotron were investigated. Three different lattices, with 12, 16 and 20 'FODO' cells were studied and costed. This paper presents the parameters obtained for the three lattices and the resulting cost variations.

1 INTRODUCTION

The parameters of a booster synchrotron intended as a pre-injector for a larger accelerator are constrained only between broad limits determined by the feasibility of design and operation. However the economics of building and operating the booster will determine the choice of parameters far more precisely; there will be a particular design which gives an overall circumference, magnet field strength, etc., which minimises the capital outlay.

In the standard approach, the booster would be compact, smaller than the main ring, with higher peak bending fields and a simpler lattice. Exact details would depend on the particles being accelerated, electrons having significant radiation loss in high magnetic fields. Notwithstanding, it was still the norm for electron boosters to be appreciably smaller than the main facility.

This tradition was overturned by the design of the booster synchrotron for the Swiss Light Source (SLS) currently nearing completion [1]. This utilises a booster synchrotron located in the main storage ring tunnel, with almost identical circumference. Major design advantages are thus obtained:

- the long, low field bending magnets have lower peak energy, leading to reduced energy storage in the main power supplies;
- the total r.f. power is substantially reduced, there being lower dipole synchrotron radiation power;
- high gradients can be incorporated into the low field bending magnets giving a combined function lattice without individual quadrupoles.

During the initial work for the proposed 3 GeV UK synchrotron source 'DIAMOND' and the design of the full-energy booster synchrotron, the example presented by the SLS was debated. Given the requirements for this project, would a traditional compact design provide the cheapest booster, or should a large diameter, low field machine be pursued? To resolve this, the study described below was carried out to examine three different ring sizes and lattices and to cost these examples.

2 SCOPE OF THE STUDY

2.1 Project Constraints

At the commencement of the work, the basic philosophy for the project presented three fundamental criteria which were to be satisfied:

- unrestricted access was required separately to both the booster and the storage ring, irrespective of the operational status of the other machine; this implied that the booster would need to be in a separate tunnel to the storage ring;
- there should be no danger of the stray oscillating magnetic fields from the booster interacting with the beam in the storage ring;
- the booster must be an 'easy to operate' accelerator.

The first of these criteria represents a radical departure from the philosophy adopted for the SLS, where the booster is located in the same tunnel as the storage ring and hence does not require separate shielding or engineering services.

2.2 Choice of Reference Designs.

Earlier work on the 3 GeV booster had been based on a twelve cell FODO lattice, with a ~ 125m circumference. This early booster had a dipole field of 1.13T with high energy storage requirements in the magnet power supplies and appreciable r.f. power demands. It was decided that this would represent the smallest design to be considered.

It was planned to locate the booster synchrotron in the central circular area inside of the storage ring; at that time a single dome to house the complete facility was proposed. A preliminary study of equipment layout indicated that with a 397 m circumference storage ring, the largest FODO lattice booster which could be accommodated was a 20 cell arrangement. A decision was therefore taken to study the engineering and costs of three distinct lattices having 12, 16 and 20 cells.

The basic parameters of these three reference designs are given in Table 1. The scaling was based on a fixed dipole magnet length of 2.32 m for all three cases. It will be noted that as the number of electrons required per pulse is constant, the larger circumference designs have lower circulating beam currents.

Table 1: Parameters of the three reference designs chosen for study

Number of cells	12	16	20
Number of dipoles	24	32	40
Circumference (m)	126.6	168.8	211.0
Peak dipole field (T)	1.13	0.85	0.68
Beam current (mA)	20	15	12
Peak volts loss/turn (kV)	808	606	484
Radiated power density into vessel wall (W/m)	40.6	17.1	8.8

3 THE LATTICES

Three separated function lattices were studied, all featuring the same cell design. With reasonable values for magnet strengths, the full energy emittance and the lattice beta functions, the stable operating regions for the three lattices were found to be:

- 12 cells: $5.3 \leq Qr \leq 6.8$; $2.2 \leq Qv \leq 4.7$
- 16 cells: $5.3 \leq Qr \leq 7.9$; $2.8 \leq Qv \leq 6.8$
- 20 cells: $5.3 \leq Qr \leq 9.0$; $3.2 \leq Qv \leq 8.5$

In addition, a nominal working point was chosen for each lattice. This was based on three criteria:

- minimising the sensitivity to closed orbit errors; this entails avoiding near-integer tune points;
- avoiding structural resonances;
- choosing a radial tune convenient for injection.

The nominal tune points and selected other parameters are given in Table 2.

Table 2: Parameters at 3 GeV for the three lattices chosen for study.

Number of cells	12	16	20
Nominal radial tune	6.37	7.43	8.62
Nominal vertical tune	3.38	3.45	4.73
Momentum compaction	0.0246	0.0178	0.0133
Radial emittance (nm.rad)	118	72.7	46.6
F quad gradient (T/m)	14.9	13.0	12.3
D quad gradient (T/m)	14.8	12.9	13.1

Using commonly accepted values for errors in the fields and positions of the magnetic elements, the aperture requirements for the three lattices operating across the full ranges of tune values were established; these are shown in Table 3. The magnet geometry requirements (taking vacuum vessel dimensions and engineering tolerances into consideration), are also shown.

Table 3: Aperture requirements (in mm) for the 12, 16 and 20 cell lattices.

Number of cells	12	16	20
Dipole horizontal ½ aperture	15.7	19.1	21.4
Dipole vertical ½ aperture	13.3	14.0	14.2
Dipole total gap	35	37	37
F quad horizontal ½ aperture	17.1	20.4	22.8
F quad vertical ½ aperture	8.8	9.9	10.6
D quad horizontal ½ aperture	9.1	12.9	14.0
D quad vertical ½ aperture	13.8	14.6	14.7
F & D quad inscribed radii	20	22.3	23.8

During the aperture estimates it became clear that whilst the lattices with larger numbers of cells offered smaller high energy emittances after full damping had occurred, the apertures at injection were determined by the emittance of the undamped beam from the 100 MeV pre-injector.

It can be seen that whilst the lattices with the larger number of cells generally have weaker magnetic elements, they require greater magnet apertures. However, the larger rings have greater operational flexibility and could therefore provide more choice of working point, with possible areas of easier, less critical operation.

4 ENGINEERING COSTINGS

As expected, some systems showed a relaxation in operational parameters with increased size of booster. The dipole energy storage requirements decreased, resulting in some reduction in the power supply costs, but the increased number of dipole magnets cancelled out the reduction in cost per unit. There was little change in the design of the quadrupole magnets with increased lattice size and, again, the increase in the number of individual units resulted in higher costs. Because of the lower radiation density in the larger lattices, radiation absorbers are not required and less pumping speed per cell is needed. So, in spite of increased length, the vacuum system costs were nearly independent of cell number. All other major systems, including controls, mechanical and electrical services and shielding, show increases in capital cost for the larger lattices. Only in the case of the r.f. system was there a significant reduction in the operational parameters and hence cost. The r.f. system requirements are shown in Table 4. The variations in the estimated capital cost for the major systems, plotted as a percentage

Table 4: R.f. requirements for the three lattices.

Number of cells	12	16	20
Cavity volts (MV)	1.5	1.0	0.75
Number of cavities	2	2	1
Power (kW)	172	73	76
Klystrons	1 super power klystron	2 TV transmitters	2 TV transmitters

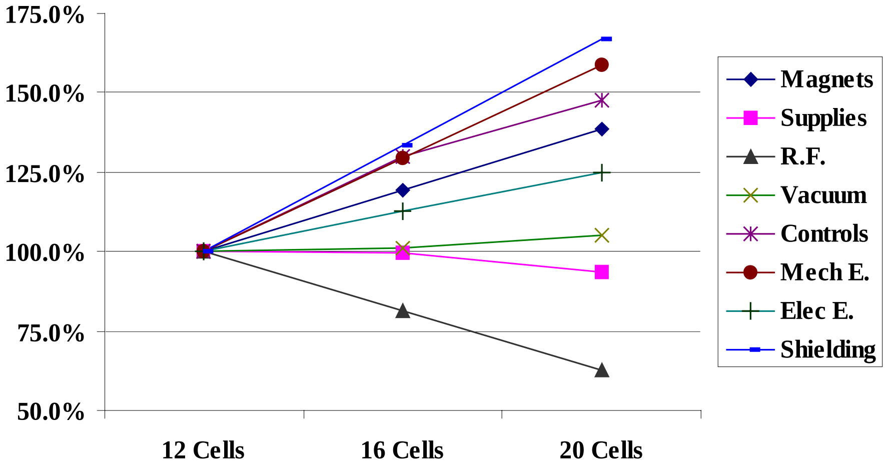

Figure1: Variation with lattice size of the cost of the main booster systems as a percentage of their 12 cell costs.

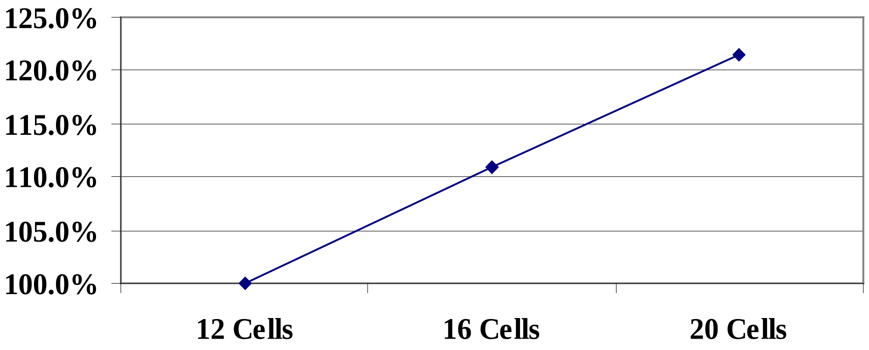

Figure 2: Variation with lattice size of the cost of the complete booster as a percentage of the 12 cell cost.

of the cost for the 12 cell alternative, are shown in Fig 1. The resulting estimate of the variation in capital cost for the complete booster is shown in Fig 2.

5 CONCLUSION

The cost estimates indicate that, with the assumptions made at the beginning of this exercise, the 12 cell booster is the cheapest option, with the 20 cell case being approximately 20% more expensive. Refinements in the lattice design could have further reduced the cost of the larger boosters; for example, it would have been possible to use combined function dipole/quadrupole magnets, to eliminate the cost of the individual quadrupoles. However, the latest developments in the plans for the project include an increase in the size of the storage ring, to accommodate a 24 cell lattice. This will almost certainly result in the booster synchrotron being located in a separate building. The higher civil engineering costs associated with a large diameter booster would then certainly reverse any savings made in accelerator systems. It is therefore concluded that, with these constraints placed on the design of the DIAMOND booster, the smallest accelerator which is technically possible represents the most economic choice.

REFERENCES

[1] W.Joho et al., ‘The SLS Booster Synchrotron’, Proc of the EPAC98, Stockholm, June 1998, p 584.