# THE CHOICE OF POWER CONVERTER SYSTEMS FOR A 3 GEV BOOSTER SYNCHROTRON

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*Abstract*

The design for the proposed UK synchrotron light source, DIAMOND, includes a 3 GeV booster synchrotron for full energy injection. Studies have been carried out to determine the most suitable power converter systems for the single dipole circuit and the two separate quadrupole families. Particularly, the choice between a direct connection to the public supply system as opposed to an energy storage configuration, such as the "White Circuit", was examined. The paper will include details of this study and present the conclusions determined by technical and economic suitability.

## 1 INTRODUCTION

The design of the proposed DIAMOND synchrotron light source [1] has been enhanced by the inclusion of a full energy injector. This requires a 3 GeV booster synchrotron, and studies have been made of ways of powering this machine. The choice of resonant excitation or direct connection to the local electricity supply network is fundamental to the machine. We were given a lattice design, described at the time as "aggressively compact", and asked to compare power converter systems for it at a cycling rate of 5hz. The object was to see whether, for a machine which would operate only for short periods, the cost of plant with increased power ratings was outweighed by savings in the civil engineering and those items whose cost is dependent on the circumference of the accelerator, such as the vacuum system.

The design revealed a number of problems, resulting in a second specification being produced which has now been developed to the stage where power converter parameters can be compared with the first design.

The comparison has been made assuming that a biased sinewave is used to excite the magnets, although in practice, a directly connected system would ramp the magnet current, perhaps with a different waveform.

## 2 THE "SUPER COMPACT" DESIGN

### *2.1 The Magnet Lattice*

A separated function lattice was produced, and this paper presents only the dipole and quadrupole data, since the sextupoles do not have significant stored energy. Table 1 shows the electrical characteristics of these magnets.

Table 1. Parameters for First Design

| | Dipoles | 'F' Quads | 'D' Quads | |
|---|---|---|---|---|
| Number | 20 | 20 | 20 | |
| Peak Current | 968 | 200 | 140 | A |
| Circuit inductance | 586 | 180 | 116 | mH |
| Circuit resistance | 0.3 | 0.9 | 1.1 | W |
| Circuit Peak Stored Energy | 275 | 3.6 | 1.1 | kJ |

### *2.2 Magnet Power Requirements*

Considering first a resonant solution, the parameters for a "White Circuit"[2] operating at 5Hz were calculated for the dipoles. When budgetary costs for this design were sought, it quickly became apparent that the energy storage choke required was in fact larger than that of the ESRF 6GeV booster synchrotron, and likely to cost in excess of £ 300,000. The capacitor banks were rather more modest, at about £ 60,000.

### *2.3 The RF Power Requirement*

When considering the options available for powering the machine, the RF power duty cycle must be taken into consideration, since it also represents a fluctuating, if non-reversing power cycle. The RF power waveform was calculated, and from this the power input to a klystron with an assumed efficiency of 60% was added to the magnet power requirement.

### *2.4 Direct Connection Option*

Having combined the magnet and RF power requirements the total power cycle shown in Figure 1 was obtained.

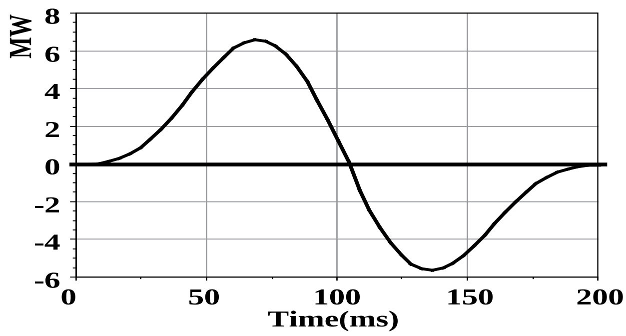


Figure 1 Total Power Cycle for First Design

It was deduced that if the DIAMOND storage ring magnets and RF were energised, this would not result in reversal of power flow to the site, but if only the booster were energised, then reversal would occur. Discussions took place with the local electricity distribution company. Their primary concern was flicker on the supplies to the surrounding villages, and advised that if such a machine were to be constructed, the fault level to the Daresbury site would need to be raised from the present level of 250MVA to in excess of 2000 MVA.

## 3 THE MORE CONVENTIONAL DESIGN.

### *3.1 Magnet parameters.*

With the high power ratings resulting from the early magnet design, a lattice with a larger circumference and a significantly smaller beam dimensions was investigated [3]; the reduction in field and aperture would clearly lead to a lower stored energy in all the circuits. Parameters for these magnets are:

**Dipole Magnets:**

| | |
|---|---|
| Number of magnets | 24; |
| Peak field | 1.15 T; |
| Magnetic length | 2.32 m; |
| Horizontal good field aperture | ± 18 mm; |
| Magnet half gap at orbit | 16 mm. |

Table 1: Quadrupole magnets:

| | 'F' Quads | 'D' Quads | |
|---|---|---|---|
| No. of quads | 24 | 24 | |
| Peak gradient | 14.9 | 14.9 | T/m |
| Magnet length | 0.38 | 0.28 | m |
| Inscribed radius | 22.0 | 22.0 | mm |

### *3.2 Power converter ratings*

Detailed field investigations and flux calculations are still to be carried out, but preliminary estimates result in the following values for the power requirements, on which an assessment can be based. The figures assume biased sinewave excitation at 5Hz.

Dipole coils and power converter:

| | |
|---|---|
| Number of coils per magnet | 2; |
| Turns per coil | 20; |
| Peak current | 731 A; |
| Total circuit inductance | 448 mH; |
| Total circuit stored energy | 121 kJ; |
| Total circuit resistance | 0.95 W; |
| Circuit alternating reactive voltage | 3.6 kV(rms). |

Table 2: Quadrupole Coils and Supplies:

| | 'F' Quads | 'D' Quads | |
|---|---|---|---|
| No. of coils/mag | 4 | 4 | |
| No. of turns/coil | 10 | 10 | |
| Peak current | 286 | 286 | A |
| Circuit inductance | 29.9 | 21.6 | mH |
| Circuit Stored Energy | 1.23 | 0.89 | kJ |
| Circuit resistance. | 0.45 | 0.34 | W |
| Circuit react. volts | 95 | 69 | V (rms). |

These parameters are a significant reduction on those previously assumed. In particular, the stored energy in the dipoles has been reduced to less than 50% compared to the earlier design, and the possibility of a direct connection for the total load was further investigated. Figure 2 shows the power cycles for all of the major systems on the machine

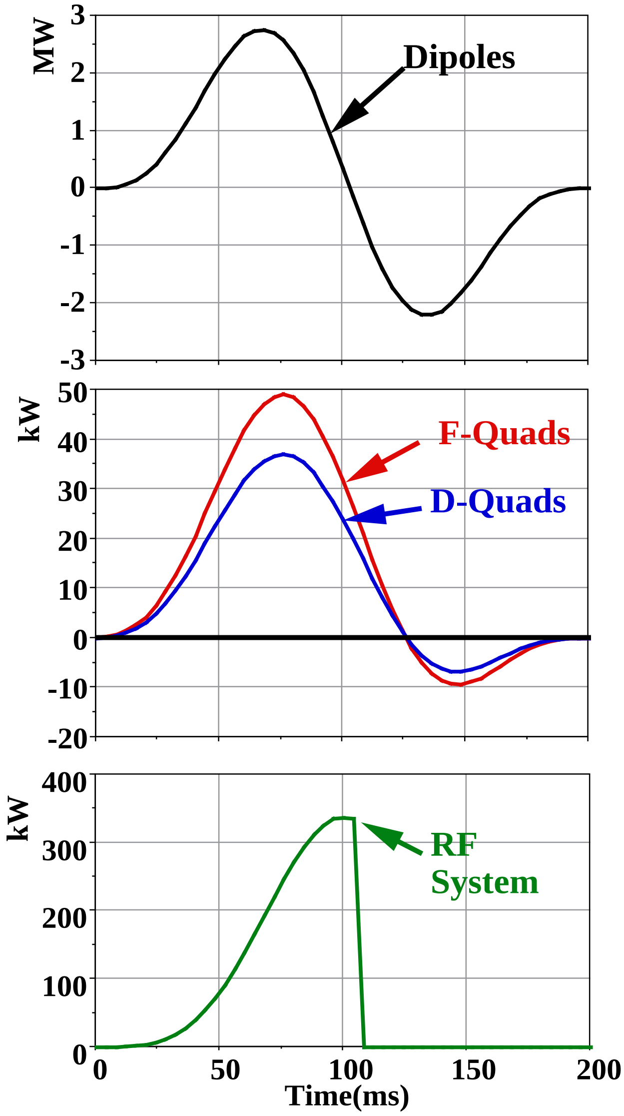


Figure 2: Magnet & RF Power Cycles

### *3.3 The RF Power Requirement*

The larger circumference has reduced the RF accelerating voltage. This could have allowed a reduction in the RF power requirement, but instead it was decided to reduce the number of accelerating cavities from three to two. The resulting reduction in shunt impedance has meant that the required RF power has stayed almost constant.

## 4 POWER CONSIDERATIONS

### *4.1 The Site Supply*

The laboratory is presently fed via a 33kV ring main with two 33kV/11kV transformers in a substation of the local electricity distribution company on the Daresbury site. These are normally paralleled at 11kV via a bus-section, and several local villages as well as the laboratory receive feeds at 11kV. Figure 3 shows this arrangement.

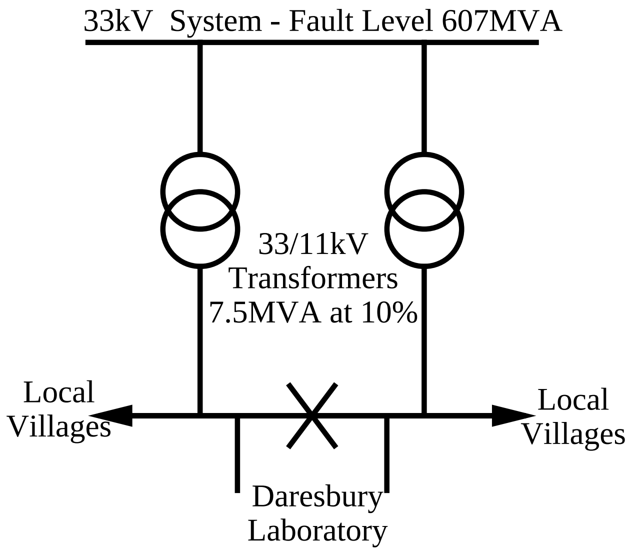


Figure 3: Local Electricity Distribution

### *4.2 Direct Connection Option*

If one of these transformers could be dedicated to the pulsed loads, the current lattice design would result in a voltage depression of approximately 4.5% on the 11kV side and a 0.49% depression on the 33kV system. Advice now indicates that the flicker severity on the 33kV system would just reach the allowable limit, and the local electricity company would require a safety margin which equates to a 0.28% depression, since the laboratory is not the only source of flicker. This implies that a fault level in excess of 1530MVA is needed, and therefore requiring a 132kV connection. Since this would cost about £1 million, it is obviously not viable.

The alternative strategy would be to drastically reduce the cycling rate, to about 2Hz, but even then a third 33kV/11kV transformer would be needed at a cost of about £150,000. This is not considered an attractive option.

### *4.3 White Circuit Option*

The White Circuit option for the new lattice has still to be costed, but it is believed that the price of the reactive components will be comparable to the provision of the extra transformer. However, it is now considered that the best solution is to utilise the White system for the dipole circuit, and use a directly connected fast tracking rectifier/inverter for the quadrupoles. This option appears to be economically superior and provides the most flexible regime for machine operation.

Having drawn this conclusion, only a small penalty is incurred if the frequency is doubled to 10Hz. The dipole circuit alternating reactive voltage would double to 7.3kV rms, (3.6kV rms to earth) which is still reasonable for coil insulation.

It remains to be shown whether changing to a two section White Circuit is economically worthwhile. The capacitor banks would cost about the same, the choke would be slightly more expensive, but the magnet coils would be less expensive because the peak voltage to earth would be halved.

## 5 CONCLUSIONS

In order to comfortably meet the specifications on flicker imposed by the local electricity supply company, a direct connection to the mains would require the repetition rate of the booster to be limited to about 2Hz. Even then, the costs incurred in providing an extra supply at 33kV are comparable with those of the reactive components for a resonant solution. We conclude that the White Circuit at 10Hz is the best solution.

## 6 ACKNOWLEDGEMENT

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## 7 REFERENCES

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[2] J A Fox, Proc IEE, Vol 112, p.1107, 1965

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