PULSED MAGNETS AND PULSER UNITS FOR THE BOOSTER AND STORAGE RING OF THE DIAMOND LIGHT SOURCE

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Abstract

The Diamond booster and storage ring facility has ten pulsed magnet systems, five for the booster (injection and extraction) and five for the storage ring (injection septum and four bump kickers). Each has its own specific requirements although commonality of design has been adopted where possible. Design and construction principles and results of magnet and pulser testing are discussed as is the first use of the magnet systems during beam commissioning.

INTRODUCTION

Two groups of pulsed magnets, pulsers and chambers were developed for Diamond, one set for injection and extraction in the Diamond booster and the other set for injection and production of a closed orbit injection bump in the storage ring. In both cases this led to two distinct classes of pulsed magnets – slow septum magnets using a full period sine wave and kicker magnets using fast pulses tailored to the beam application. Early on the conceptual design decision was taken to make the driver pulser unit for each magnet system local to the magnet i.e. inside the machine vaults, with a separate HV charger unit and controls located some distance away in a control and instrumentation area outside of the vaults.

MAGNET REQUIREMENTS AND PROCUREMENT

It was decided that the most satisfactory way to proceed with procurement was to purchase an integrated magnet system built with the pulser unit adjacent or beneath the magnet - this eliminated uncertainties about matching and ensured the load (magnet) was tested with its final drive circuitry by a supplier in its final configuration. A specification and procurement exercise commenced with two separate invitations to tender: all 5 units for the booster then later all 5 units for the storage ring. Both contracts were finally let to Danfysik who sublet a contract to Puls-PlasmaTechnik, Dortmund (PPT) for the faster pulsers. The Danfysik design approach also solved directly concerns DLS had about septum magnet laminations in vacuum, as they used thin wall stainless steel vessels inside the magnets. A specific requirement for all 10 magnets was that they met their design field, then they were to be designed and tested at 20% over that field so that there was a large design margin and the magnets and pulsers would routinely operate in a less stressed condition than might be seen at the design limit.

MAGNET SPECIFICATIONS

Booster Injection and Extraction Kickers

These magnets have either fast fall or fast rise times for the injection and extraction processes respectively, but the field demands on them are very different. For both of these magnets a ferrite based single turn magnet was constructed and as there were no particular problems doing so with booster vacuum requirements, the magnets were constructed to be installed *in vacuum* inside a cylindrical stainless steel vacuum vessel and driven through HV feed-throughs to the pulser unit beneath them. Both kickers use thyratron based switching technology within the pulser.

Table 1: Booster Injection and Extraction Kickers

Parameter	**Booster Inject Kicker (BIK)**	**Booster Extract Kicker (BEK)**
Deflection angle	4.5 mrad	30mrad
Peak field	5mT	30mT
Magnetic length	300mms	1000mms
Beam clear aperture (h xv)	16 x 14 mms	33 x 14 mms
Repetition rate	5 Hz	5 Hz
Field waveform	Flat top 380ns	Flat top 380ns
Field rise time	Not critical	150ns
Field fall time	150ns	Not critical
Flat top ripple	< 1%	< 1%
N turn coil	1	1
Nominal drive current	65A	350A

The extraction kicker is the more highly stressed of the two systems, it also uses an external coax cable as part of its pulse forming network. Table one lists the key parameters of both systems and all of these parameters were met on Acceptance of the units, with magnetic length fractionally longer than designed.

Booster Septa

The septa were all constructed in a similar style – a thin walled stainless steel vessel passes through the magnet aperture and a Ni coated mild steel vacuum vessel shields the passing beam from stray field from the septum magnets main field. This type of septum construction gives very low stray field outside of the septum face, keeps the surface area of material inside the vacuum system at an absolute minimum and makes the magnet easy to service and maintain as it is all out of vacuum. The only limitation is that a fully assembled magnet is difficult to bake much above 70°C because the thin walled vessel has to be supported by reinforcement externally with epoxy resin to not distort under atmospheric pressure.

Table 2: Booster Injection and Extraction Septa

Parameter	**Booster Inject Septum (BIS)**	**Booster Extract Pre Septum (BEPS)**	**Booster Extract Septum (BES)**
Deflection angle	275 mrad	4.7mrad	108mrad
Peak field	310mT	130mT	900mT
Magnetic length	300mms	360mms	1200mms
Beam clear aperture (h x v) magnet	20 x 15 mms	16 x 10 mms	16 x 10 mms
Repetition rate	5 Hz	5 Hz	5 Hz
Field waveform	Full Sine	Full Sine	Full Sine
Septum thickness	3+/-.5 mms	3+/-.5 mms	3+/-.5 mms
Stray field outside septum	< 30μTm	< 30μTm	< 30μTm
Nominal peak drive current	3800 A	1400A	7500A
N turn coil	1	1	1
Water cooling	No	No	Yes

Table 2 represents the specified values for the magnets and again except for minor increases in Magnetic lengths, the as delivered magnets met or exceeded these specifications.

Measurement of Booster Magnets

All booster magnets were measured with integrating search coils. As the data shows them very much in specification the details are not shown here. For measurements of stray field for the septum magnets a more sensitive long integrating coil was used. Essentially measurement could be made at about the 5 parts in 10^4 level which was as accurate as the coil/scope combination could achieve. The stray field measurement did show a 'shorted turn' problem initially which required the vacuum vessel to be isolated one end, this also showed up as local heating. Isolation of the chamber completely eliminated this. All booster magnets are now in routine use whilst beam commissioning of the booster approaches completion [1].

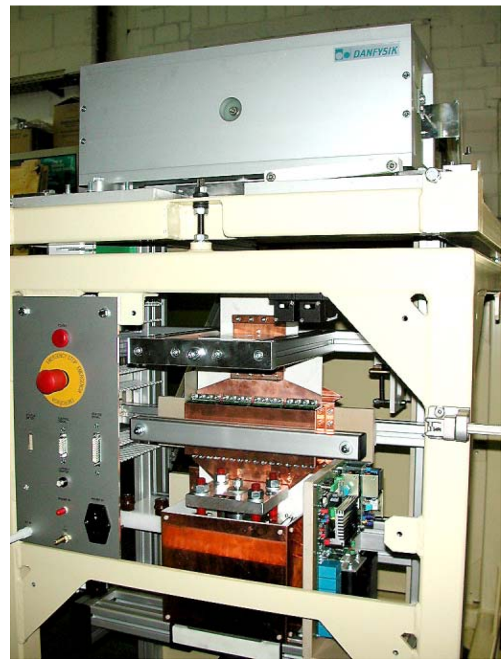

Figure 1: Storage ring injection kicker, magnet upper, pulser below, variable tuning inductance centre.

Storage Ring Septum Magnet

This septum magnet followed the same construction principles as the Booster extraction and injection septa, because of space and bend angle constraints it could not be identical to Booster Extraction Main Septum (BEMS).

This magnet was designed to be translatable i.e. the position of the septum face can be moved parallel relative to the circulating beam centre line over a range of 8 mms. This is achieved by translating the entire magnet and its pulser from its base and permitting the movement on canted bellows sections in the injection straight, to maintain parallel motion it is necessary to move along the angle of the incoming beam. Whilst this cannot be carried out remotely it can be done quickly within a few hours without opening up the storage ring vacuum.

Storage Ring Kickers

The four storage ring kickers were designed to be identical in all aspects except for polarity of energisation. The specified parameters are listed in table 3. The importance of maintaining identical pulse amplitude and timing performance and hence kick field seen by the electron beam both injected and circulating was an important part of their specification and testing. Essentially there are three variables used to tune up the pulser/magnet combination, the peak amplitude, the relative timing and an adjustable inductor on each unit that can be used to match pulse lengths to each other. The pulser unit Figure 1 consists of a thyristor switch stack (four Dynex PT60QHx45 in series) and a capacitor bank constructed from a series and parallel combination of twenty 125µF/4kV FPX86Y1254J capacitors from the company AVX / TPC.

Despite a good match of the current waveforms across the 4 units beam tests performed in May 06 in the storage ring imply that there may be time differences in the peaks of *current peak to field peak* i.e. a phase difference by up to 140ns and this may be due to differences in metallic coating of the ceramic chambers, discussed later.

Table 3: Storage Ring Kickers and Septum Magnet.

Parameter	Storage Ring Kickers (SIK1-4)	Storage ring Septum (SIS)
Number	4 units	1 unit
Deflection angle	9.6 mrad	150mrad
Peak field	160mT	894mT
Magnetic length	600mm	1670mm
Beam stay clear aperture (h xv)	23 x 80 mms	20 x 15 mms
Repetition rate	5 Hz	5Hz
Field waveform	½ Sine wave	Full sine wave
Field rise time	2.5µs	140µs
Field fall time	2.5µs	140µs
Flat top ripple	< 1%	< 1%
Stray field outside septa	N/A	< 30µTm
Nominal drive current	5kA	12.75kA
Vacuum chamber	Alumina/Ti coated inside 600µm	Magnet outside vacuum

Looking at the current pulse signals in difference (subtracting one pulser's current waveform from another's) mode, lower trace on Figure 2, while performing beam tests with the kickers a ½ µs deviation at the leading edge of the pulse *difference* has a larger than anticipated deviation. This appears to be due to differences in the time thyristors are turning on or driven and is being investigated. The upper trace of Figure 2 is the 4 current waveforms SIK1-4 overlaid simultaneously.

Coating the kicker ceramic chambers proved more difficult than anticipated and the plan to have measured all 4 magnets with integral coils inside each coated chamber proved impossible to achieve directly due to installation pressures, although indirect data was taken. Some of the Ti coatings suffered unexpected adhesion problems and whilst matched to each other in terms of resistance, (3Ω) the visible (by transparency) uniformity across the chamber indicated process problems. The coating method is due to be switched to a magnetron coating process from evaporative and replacement chambers fitted.

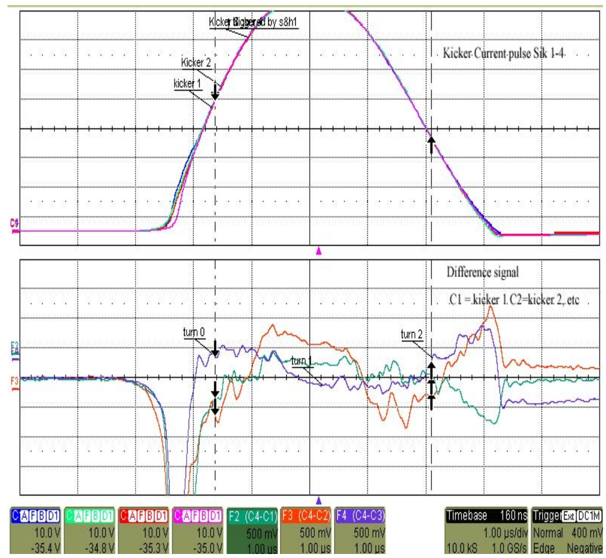

Figure 2: SIK1-4 (upper) and differences (lower) in pairs. Max current peak ¼ of design value for injection.

SUMMARY

Diamond's family of 10 pulsed magnets have been procured, factory tested, installed in their final location, power tested and used for injection or extraction of the Diamond injector beam including into the storage ring. Development issues were obtaining clean pulsed magnet measurements, vacuum vessels producing single turn short effects in septa and development problems with ceramic chamber Ti coatings on the vacuum vessels for the storage ring.

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REFERENCES

[1] V.C.Kempson et al "Commissioning of the Diamond Booster Synchrotron for the Diamond Light Source", these proceedings.