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THE BEAM SHARING PROJECT OF THE HAMMERSMITH CYCLOTRON

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Abstract. - Development has been proceeding on a beam sharing project involving a "kicker magnet" (rapidly pulsed bending magnet) and d.c. septum magnets in order to simultaneously irradiate more than one external target. When beam currents are target limited this technique can be used to increase radionuclide production. The technique has been proved experimentally and development for routine radioisotope production is now in progress.

1. Introduction. - The beam currents which can be extracted from the Hammersmith cyclotron are well in excess of those necessary to meet the biomedical requirements of this cyclotron. It is therefore possible to share the extracted beam between a number of beam lines in a manner which allows the simultaneous use of multiple external target positions. Such a facility would allow an extension of the application of the cyclotron by, for example, allowing the simultaneous controlled production of different radionuclides.

In an earlier paper[1)] it had been proposed that simultaneous beams could be achieved by the use of a "kicker magnet" to produce pulsed deflection in the horizontal plane, to "kick" the extracted beam of the cyclotron sequentially into septum magnets. These would further deflect the beam into three parallel beam lines (fig.1).

The beam transport system of the Hammersmith cyclotron has been rebuilt to accommodate such a beam sharing facility. The necessary ferrite cored kicker magnet, prototype pulsed power supply and D.C. septum magnets have been developed. Initial tests using low beam currents have shown successful operation of the facility.

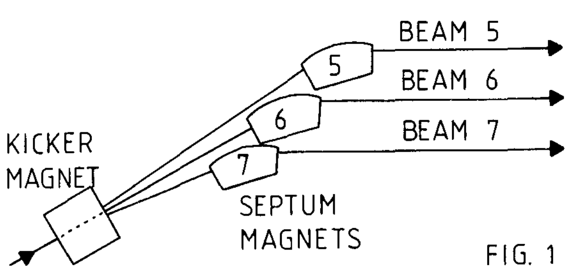

Fig.1: Three way beam sharing.

2. The Beam Sharing Facility. - The beam sharing facility is incorporated along a beam line which originally served a single radionuclide production facility. It is designed to bring three parallel beam lines into a target room external to the cyclotron vault. (Beam 5, Beam 6, Beam 7, fig.1). Each of these beam lines incorporates a septum magnet suitably positioned along the original beam trajectory but laterally displaced to accept the appropriate kicked beam. A kicker magnet is positioned at the beginning of the beam transport system beam line in order to allow adequate lateral displacement at the first septum magnet.

The beam sharing facility has been designed for a horizontal beam emittance of 15π mm-mrad. For the settings chosen of the beam transport elements in the beam line, the average horizontal emittance ellipse of the cyclotron (34+ j.192 in Hereward's complex number notation ref.2 & 3) gives estimated beam widths of 5 mm at the entrance to beam 7 septum magnet, and 13 mm at the entrance to beam 6 septum magnet. The nominal width of the current septum in the septum magnets is 20 mm allowing for conductor, insulation and beam protection. The kicker magnet system therefore has been designed to produce a "kick" of ±40 mm minimum from the nominal trajectory of the beam at the entrances to the septum magnets.

The requirements for pulsing of the field of the kicker magnet are dictated by (i) the duration of beam down any beam-line should be short compared with the thermal time constant of any foil or target system encountered by the particle beam and (ii) the rise time of the field should be short compared to the duration of the pulse in order that beam loss during the "kicking" between beam lines is kept to an acceptable level. A pulse duration < 100 msec with a field rise time ∿ 1% of the pulse duration was specified.

2.1. Kicker Magnet. - The kicker magnet is a simple window-frame magnet constructed from Philips 3C6 Grade ferrite and a pair of saddleback coils of 4 mm x 4 mm hollow copper conductor giving a total of 32 turns. The ferrite length of the magnet is 100 mm and the gap is 18 mm. The measured effective length of the magnet is 120 mm.

At Hammersmith the kicker magnet has to be positioned within the fringe field of the main magnet of the cyclotron, and differences in the excitation curve of the kicker magnet are noticed when the fringe field is aiding or opposing the required field of the kicker magnet. At 150 amps kicker magnet current a field of .25T is obtained with adding fringe field and .22T with opposing fringe field. Also a modification of the inductance of the kicker magnet is seen.

For the 40 mm kicks specified for the beam sharing project, 30 mrad deflection is required for Beam 7 and 23.2 mrad for Beam 5. At the rigidity of the Hammersmith cyclotron external beam, viz. .82 Tesla metre, and for the effective length of the kicker magnet, the fields required are .2 Tesla and .16 Tesla respectively.

2.2. Septum Magnet. - The septum magnet design is of a standard "C" type with a thick current sheet as the boundary between the uniform field area inside the gap and the near zero field region outside the gap. The magnet is required to give a deflection of .52 radians (30 degrees) to the .82 Tesla metre beam. This is achieved with a field of 1 Tesla in the gap. The magnet has a gap of 18 mm a beam window of 60 mm width, and an effective length of 440 mm. The coil of the magnet comprises a curved thick current septum formed from a 4 x 4 matrix of 4 mm x 4 mm hollow copper conductors with a return conductor formed from a 2 x 8 matrix of 8 mm x 8 mm hollow copper conductors. All conductors are series connected electrically to produce a 16 turn coil. However, 8 parallel water cooling paths are formed in order to provide adequate water flow through the narrow bore conductors to remove the high power dissipated in the current septum. The power consumption for one magnet is 25 Kw at the necessary excitation current of 1000 amps. Each magnet is provided with a backleg winding of 16 turns, to allow individual fine control of the field of each magnet, since a common 1000 amp power supply is being used to excite all three magnets.

2.3. The Kicker Magnet Power Supply. - The prototype Kicker Magnet Power Supply which has been constructed and used for the initial beam tests has a pulse repetition rate of 20 Hz with equal mark space ratio and 160 μsec rise time to the current pulse. A schematic diagram is shown in fig. 2. The capacitor (C1) is charged from a high voltage source (TR1) to give rapid changes of the kicker magnet coil current and low voltage, high current supplies (CS1, CS2) are used to maintain the coil current at the required values.

The waveforms for sharing between Beam 5 and Beam 6 are shown in fig. 3. Operation is as follows:-

Before time T1	C1 charges via thyristors VT1 & VT3 to the required value. Beam down Beam 6.
At T1	C1 discharges through the kicker magnet coil having inductance L1 via thyristor VT7. The current in L1 rapidly rises.
At T2	Thyristor VT9 turns on, VT7 commutates. L1 is energized at constant current by CS1. Beam down Beam 5.
Between T2 and T3	C1 partially charges by VT1 & VT3 (dotted line), ready to give commutation of VT9 at time T3.
At T3	VT7 turns on, VT9 commutates and L1 discharges into C1 until current reaches zero at time T4. Beam now down Beam 6.
Between T4 and T5	The capacitor voltage is reversed by discharging C1 through inductance L2 using thyristor VT5 (dotted line).
Between T5 and T6	C1 is topped up to required value for start of next cycle using VT1 and VT3 (dotted line).
At T6	Cycle ready to repeat from T1.

For sharing between beams 6 and 7 the sequence is the same but with the polarities reversed, the even numbered thyristors and CS2 being used. When all 3 beams are being used the sequence would be Beam 6,5, 6,7,6 and so on. In this case the capacitor reversal cycle T4 to T5 is replaced by a top up cycle so that C1 is ready for the reverse direction.

3. Discussion. - Initial testing of the facility has been undertaken. The principle was first observed using an extremely small extracted beam current. Scintillation screens viewed by a CCTV system were used to detect the presence of particles at the end of beam lines 5 and 6. Following optimization of the main septum magnet excitation current, and one backleg winding current, fluorescence on both screens was observed indicating simultaneous particle beams in each beam line. A further test showed that with a 1:1 pulse width ratio, a beam current of 20 μA down a single beam line could be divided into two simultaneous beams of ∿ 10 μA. Improvements to instrumentation are required to determine the true efficiency of the system.

The logic for the control of the mark-space ratio is currently being adapted to allow variable ratios to control the proportion of beam current in each beam line. Future developments will involve the introduction of two-way switching to produce three simultaneous beams. Attention will also be given to the stability of the pulsed kicker magnet currents. To obtain ease of operation and stability, constant current sources with short recovery times are required to allow rapid switching between on-line and open circuit conditions.

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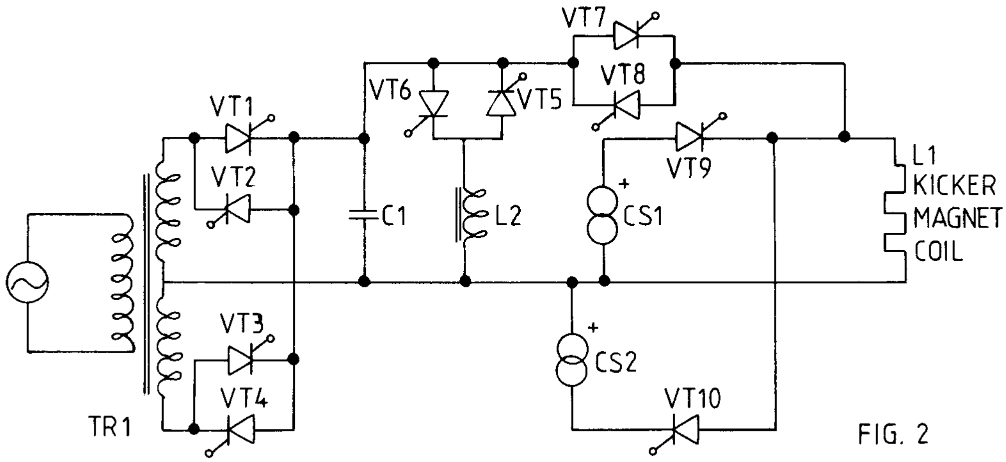

FIG. 2

Fig. 2: Schematic of Kicker Magnet Power Supply.

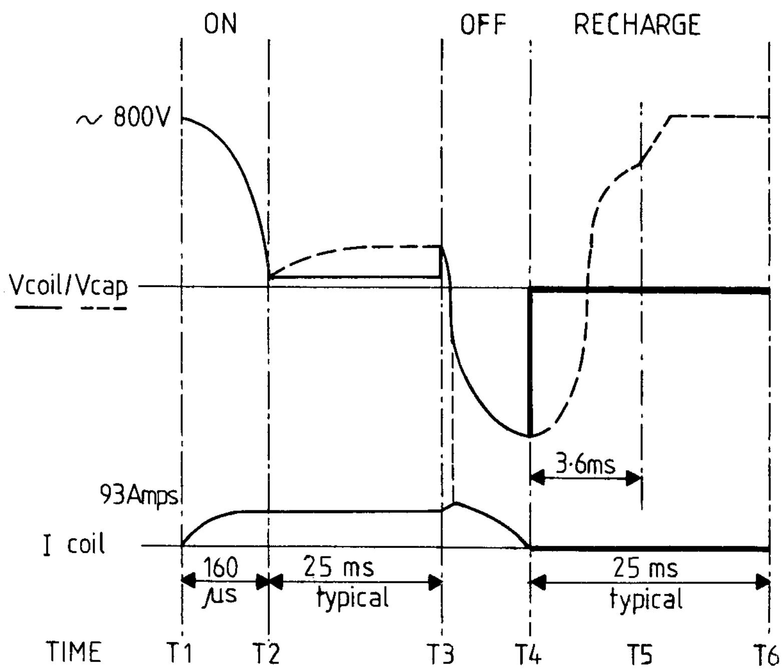

FIG. 3

Fig. 3: Waveform Diagrams for Kicker Magnet Power Supply.