Cyclotron beam sharing for multiple target irradiations

G. Burton
MRC Cyclotron Unit, Hammersmith Hospital, London

1. INTRODUCTION

Experience with the Medical Research Council Cyclotron installed at Hammersmith Hospital, London, indicates that medical cyclotrons should be capable of meeting many demands at certain times of the day. This is necessary because patient handling is only possible within certain hours. The times when on-line patient work is possible, as is required with the use of short-lived radioactive gases, or radiations involved in therapy or neutron activation are limited. In addition as the demand for medium-lived radioisotopes is developing, a number of irradiations need to be completed early to allow time for processing of the radioisotopes for clinics to be held later in the day.

By achieving more intense external beam currents than those required for most irradiations it is possible to consider the sharing of such external beams between a number of targets. The cyclotron is then capable of meeting bigger demands, and is also more economic.

This paper discusses the possibility of electromagnetic beam switching between three parallel beam lines using a low power, high repetition rate pulsed electromagnet and three high power d.c. septum magnets to give the main deflection into the beam lines.

2. THE PRINCIPLE OF BEAM SHARING

2.1. *Use of pulsed beams*

The rate of isotope production and the power dissipation within a target or within a degrading foil or machine window depend on the mean beam current over a period of time. All targets and foils where they intercept the beam have a maximum power handling capacity, but they also have an associated time constant, which causes a delay between the time of application of the power and the maximum effect produced by it. Thus high powers can be dissipated in bursts short compared with the thermal time constant of the system, but at a repetition rate such that the mean power level over a period of time is within the capacity of the system.

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Pulse length

The thermal speed of response of systems can be determined by considering the total quantity of heat required to raise the temperature of the system to a dangerous level. For instance, a 200 μA beam of 32 MeV α particles at a current density of 20 $\mu A/cm^2$ passing through a titanium foil 0·025 mm thick would raise the temperature of the foil to $1000^\circ C$ in approximately 0·26 s (assuming no cooling during the heating-up period). A water target of thickness capable of absorbing a beam of 30 MeV α particles at the same current density would be brought to boiling point in approximately 0·1 s. Allowing a factor of safety on these figures it would appear that pulse lengths around 10 ms would be suitable for a current density of 20 $\mu A/cm^2$ provided the repetition rate was such that the mean power density was within the handling capacity of the target or foil concerned.

2.2. *Beam sharing using pulsed beams*

The use of pulsed beams for beam sharing is indicated in Fig. 1. The external beam of the cyclotron enters a pulsed electromagnet, referred to as the 'kicker magnet', which serves to direct the beam into one of three septum magnets located further down the beam line. This is achieved by applying to the kicker magnet two current pulses of opposite polarity within a repetitive cycle which also contains a period of zero excitation (Fig. 2). In order to provide accurately directed, short beam pulses, the field of the kicker magnet must have an accurate flat top during the pulse and fast rise and fall times.

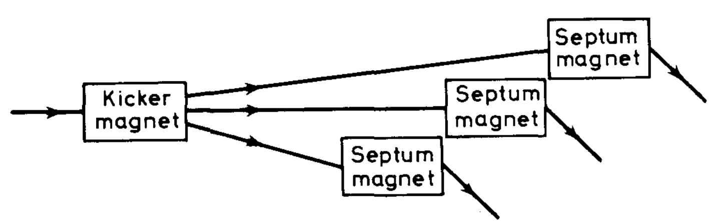

Fig. 1. Beam switching to give separate parallel beams

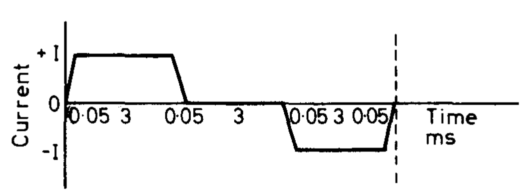

Fig. 2. Current waveform for kicker magnet

Unless one is prepared to build a large kicker magnet requiring high voltages to pulse the field, it is not possible to obtain large beam deflections, and the kicker magnet needs to be followed by further magnets to provide adequate beam separation. In Fig. 1, three septum magnets are arranged to produce three parallel beams which can travel down independent beam lines. It is also possible to have only two septum magnets arranged so that the centre beam passes straight on, and the two outer beams are deflected in opposite directions.

The strength of the pulsed field of the kicker magnet is determined by the beam displacement required at the first septum magnet, together with the beam length and any beam transport elements between these magnets. For horizontal beam sharing, the beam displacement or 'kick', must be such that there is complete separation between the three beams in horizontal cross-section, plus a gap between the beams to allow the insertion of a field defining current septum.[1]

Applied to the beam line of the MRC cyclotron, a field of 3 kG acting over a length of 10 cm would produce a deflection of 1·5°, giving a kick of approximately 7 cm at the input of the first septum magnet. This would allow a beam of 5 cm total width to be kicked with a gap of 2 cm for the current septum and clearance.

The septum magnets proposed for the MRC cyclotron would have a deflection angle of 30°, given by a field of approximately 13·5 kG over a length of 37·5 cm. This would be achieved using a multiturn septum having 16 turns of 4 mm square cross-section, hollow copper conductors in a 4 X 4 matrix giving a total septum width of 1·6 cm. The power dissipation of each magnet is expected to be 20 kW at a current of 1000 A. For three beam lines in operation simultaneously to accept the pulsed beams, the three septum magnets have to be powered continuously.

3. OPERATION OF THE SYSTEM

3.1. *Beam loss related to pulse rise time*

When a current pulse is applied to the kicker magnet, the beam moves from its undeflected position to the deflected position during the rise time of the field within the kicker magnet. During this period the beam is swept across the septum causing beam loss, heating and build-up of radioactivity. In order to reduce these undesirable effects to a minimum, the rise time of the kicker magnet field should be short compared with the cycle-time of the pulses. With full three beam sharing and a 10 ms cycle-time, a pulse rise time of 50 μs gives a beam loss of 2%; 1% of the beam being intercepted by each septum beam stop.

3.2. *Control of beam current to individual targets*

The proportion of the external beam fed to each of the three targets, and hence the beam current on each target, can be controlled by adjusting the mark/space aspect of the pulsed current power supply of the kicker magnet.

It is expected that a given beam current will be specified for each target to be irradiated, giving a total current required and the mark/space aspect of the pulses. If a change of beam current in any target is required, then the total beam current and the mark/space ratio of the pulse has to be adjusted.

The proposals for data-handling have included the presentation of individual target currents, integrated beam currents, and total beam current together with beam adjustments involving change of pulse-form and cyclotron currents.

CONCLUDING REMARKS

Beam sharing between three target positions to give simultaneous irradiation facilities appears possible using a pulsed kicker magnet and d.c. septum magnets. A project at the MRC Cyclotron Unit to investigate such a system has reached the construction stage of a ferrite kicker magnet, and drawing board stage of a septum magnet.

REFERENCES

1. Umstätter H., CERN 65-36, (1965).