DISCUSSION

BONAUDI: Would the speaker like to say something about the problem of aligning magnets, or checking the alignment of them. in the presence of high residual radioactivity?

NEET: Magnets are aligned locally. The alignment is checked by conventional techniques in the upper tunnel. Holes may be provided for this purpose in the shielding floor.

WIDERÖE: Will the X-rays produced in the collimators give rise to much trouble.

NEET: Yes they do, but I think most X-rays are absorbed locally. Radiation damage is primarily due to the shower leaking out of absorbers, and the fast neutrons.

SOME DEVELOPMENTS OF TARGETING TECHNIQUES AT NIMROD

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(Presented by D. A. Gray)

1. INTRODUCTION

The philosophy behind the provision of spill for counter beams at Nimrod has been to develop methods which rely on moving the proton beam on to targets under the influence of a rising magnetic field rather than by r.f. steering. Modulation of the spill is then caused only by the ripple on the magnet voltage and duty cycles are possible which are greater than the inherent maximum obtainable duty cycle of about 20% under r.f. steering conditions. At Nimrod, targets at a radius smaller than then beam radius have been used exclusively. Single traversal only of targets is employed.

Magnet ripple is reduced using both a dynamic ripple filter to reduce the ripple voltage across the magnet terminals and a second servo-system to reduce further the ripple field in the beam region by passing currents through the pole-face windings (1). See Figure 1.

Bubble chamber spills are obtained by programming the r.f. voltage.

All perturbations to the r.f. voltage are applied through the primary frequency generator (P.F.G.).

2. NORMAL COUNTER SPILL ON FLAT-TOP

In this technique the r.f. accelerating voltage is switched off soon after the start of flat-top. The rate of shift of proton closed orbit is proportional to dB/dt, i.e. to V - IR, V being the magnet voltage, I the magnet current, and R the

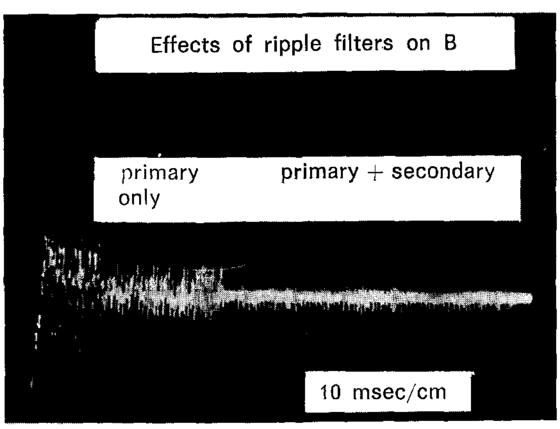

Fig. 1 - Ripple filters during flat-top.

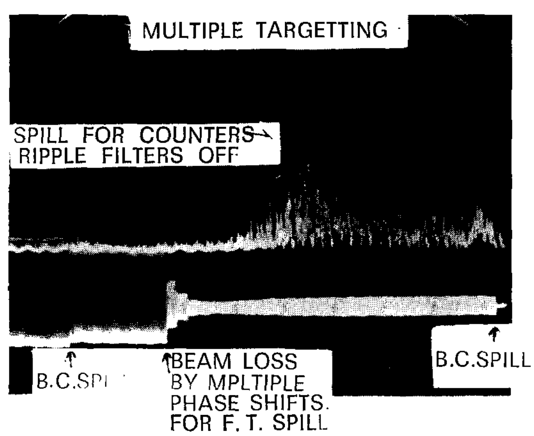

Fig. 2a - Flat-top spill. Ripple filters off.

magnet resistance. For Nimrod at 7 GeV, about 20 gauss is required to sweep all the beam on to the target. For a beam of "rectangular" distribution with radius, a uniform spill requires a constant dB/dt. The characteristic U-shape of magnet field versus time during flat-top which is caused by eddy currents in the magnet yoke (1) has been counteracted by using a fixed correction of magnet power supply inverter angle to produce a magnet voltage correction. This has produced a slope which is linear to 10% over about 370 msec with a 420 msec long flat-top. There is very little short term jitter and field slope is servo-corrected long term to be within about 2 gauss over the length of flat-top.

This technique has been used where mono-energetic primary beams are required, e.g. with the Piccioni extraction system (2). The spill at 2 GeV, without the ripple filters on, is shown in Figure 2a and Figure 2b gives the spill with both filters on.

3. NOISE SPILL ON CURRENT RISE

Some beam lines and experiments can accept a primary proton energy spread of several GeV. During some of the early operation of Nimrod this type of spill was achieved during current rise by employing foil spill (3). More uniform and reproducible conditions have been obtained by feeding white noise via a high pass filter with cut-off above the synchrotron oscillation frequency (few kc/s) into the r.f. system. This gives a perturbation of the beam in phase space and a loss of beam from r. f. trapping. The 'lost' beam then spirals on to the inside target under the influence of the rising magnetic field with less than 20% r. f. modulation of spill.

4. NOISE SPILL ON FLAT-TOP

Under conditions where some primary energy change is permissible, the flat-top slope on field may be increased and the r.f. voltage kept on. Again, noise spill is used but the modulation of the spill is reduced by the same ratio as the increase in magnet slope.

The rate of loss of beam from the r. f. fish for a constant amplitude of noise λ is given by $dN/dt = k\lambda N$, i.e. for a uniform loss of beam, an exponentially increasing amplitude of noise is required. Figure 3 shows the reproducible spill obtained at 2 GeV with a stepped noise amplitude. Work to servo the noise to produce a uniform loss of beam with time is going on.

5. BUBBLE CHAMBER SPILL DURING CURRENT RISE

In this process a sudden phase shift is imposed upon the cavity volts by applying a fast 10 μsec pulse to the P.F.G. The response of the system is such that by varying the amplitude of this pulse, phase shifts of up to several multiples of π may be induced. The time in which the phase shift occurs is so short (10 μsec) in comparison with the r.f. synchronous frequency (between 2 and 5 kc/sec) that the process is effectively instantaneous. This shift of phase gives rise to a loss of beam from the r.f. trapping, the lost particles spiralling on to the target. In this manner, with beams of about 10^{12} p.p.p., a spill time of about 500 μsec can be achieved. The method has the great advantage that, by simply varying the amplitude of the phase shifting pulse and thus of the phase shift, any required fraction of the beam may be spilled, the spill time being independent of the amount. The method has been employed successfully in all of the Saclay Chamber runs, the pulse occurring a few tens

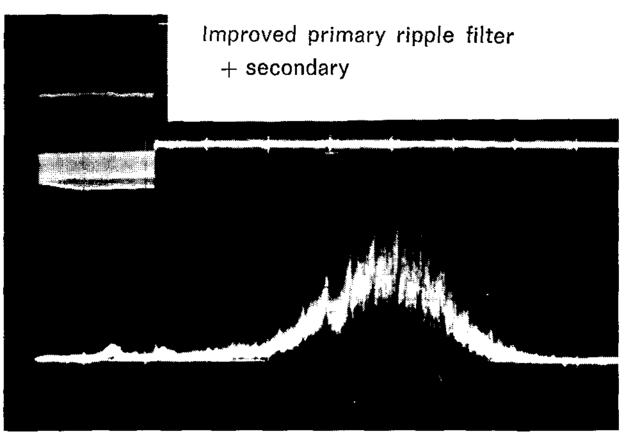

Fig. 3 - Noise spill on flat-top.

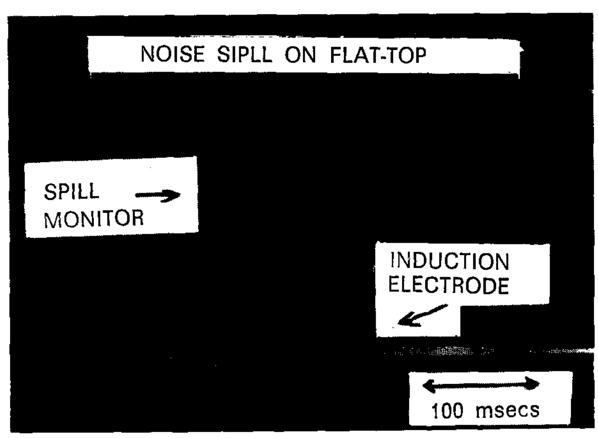

Fig. 3 - Noise spill on flat-top.

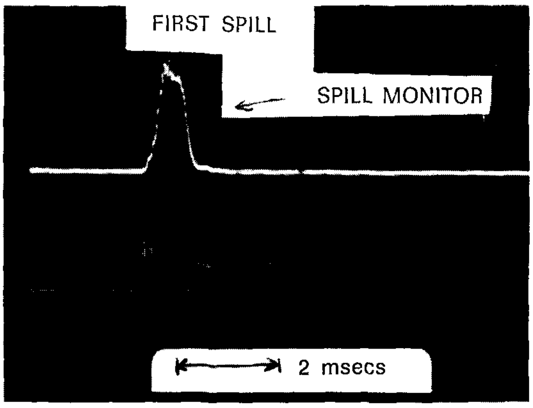

Fig. 4 - Bubble chamber spill on current rise.

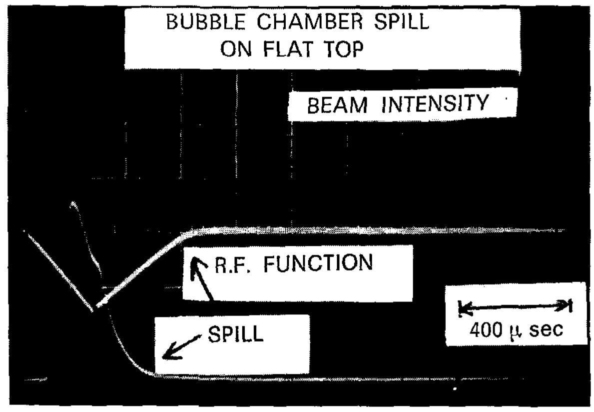

Fig. 5 - Bubble chamber spill on flat-top.

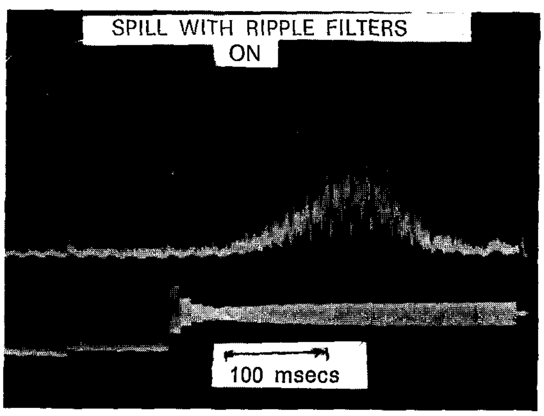

Fig. 6 - Double bubble chamber spill with counter spill.

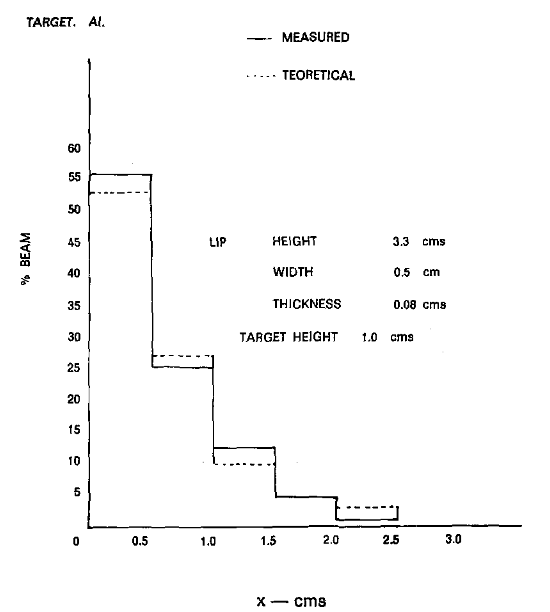

Fig. 7 - Penetration of protons into target.

of millseconds before flat-top. Figure 4 shows the spell waveform and reduction in r.f. envelope produced by such a technique.

6. BUBBLE CHAMBER SPILL DURING FLAT-TOP

The previous method is suitable only for use during current rise. On flat-top, the slow field slope means that particles lost from control of the r.f. spiral inwards extremely slowly. A problem is how to programme the r.f. such that the beam is steered on to the target in the fastest possible controllable manner.

The equation of motion of particles in the fish is of the form (4)

$$d^2\psi/dt^2 + \Omega^2\psi = \Omega^2\psi_0$$

The synchronous phase stable particle is the one for which

$$\psi_s = d\psi_s/dt = 0$$

for all t, under normal conditions. The problem is, how must ψ_0 be programmed so that ψ_s becomes $\psi_s = kt$, i.e. a linear change with time with no induced oscillations. Using Laplace Transform techniques yields as a result

$$\psi = A\delta(t) + Bt,$$

with A and B constants for a given k, i.e. a combination of a delta function and a ramp. Such a programme will cause the phase of the phase synchronous particle to change linearly with time with no induced oscillations. The fish follows and the beam moves to a smaller or a greater radius depending on the polarity of the programme.

The delta junction in ψ_o, $A\,\delta(t)$ is produced by a fast 10 μsec pulse of variable amplitude A, to the P.F.G., the area under the pulse being a measure of its effective strength. The Bt term is produced by a linear perturbation of the cavity frequency, the slope being B. The parameters A and B are independently variable and, in practice, they are tuned to achieve the optimum spill. Under these conditions, the r. f. envelope decays linearly as the beam is moved across the target, with no sign of induced synchronous oscillations. After the beam has been moved some distance in this manner, by applying a similar function of opposite polarity it may be steered away from the target. A limit is found in practice to the maximum rate of movement, this being dependent on the synchronous frequency. In Nimrod at 2 GeV, with $f_s = 5$ kc/sec, the optimum spill time is about 200 μsec for 10^{12} p.p.p. (Figure 5). At 7 GeV, with $f_s = 2$ kc/sec, it increases to about 450 μsec. The spill can be obtained anywhere during flat top; the method can also be used during current rise with a resulting decrease in spill time due to the rising field.

This method has the obvious advantage over a kicker magnet method in requiring only small scale electronics. It lends itself to control by feedback from a beam line when a sufficient number of particles has been obtained. It may also be used for multiple monoenergetic spills for bubble chamber beams.

7. NORMAL MAGNET SPILL ON FLAT-TOP RETAINING SOME TRAPPED BEAM

Where a fast burst for a bubble chamber is necessary at the end of flat-top (i.e. when a bubble chamber is double pulsing), the r.f. must be kept on to execute it. In such circumstances, a normal flat-top spill of negligible energy spread, and of controllable amount can be produced by simply phase shifting the r.f. early in flat-top. For the particles so lost, the r.f. is effectively 'turned off' at the instant of phase shift, and they spiral in slowly due to the flat-top slope, the spread in energy being insignificant. On flat-top, the width of the fish is very nearly 2π radians, so total loss of beam is impossible. By employing several phase shifts, separated by at least a synchrotron oscillation period in time, a controllable amount of beam may be lost (see Figure 6).

8. CONTINUOUS SHARING OF BEAM ON FLAT-TOP

A Montecarlo programme for tracing the orbits of particles through a target with lip (5) has shown a radial penetration into the target of about 1 cm. This has been confirmed by measuring the induced activity (α-emitter Tb^{149}) (6) in a gold foil placed on a Piccioni type target (Figure 7). Continuous sharing of beam on flat-top has therefore been possible with targets approximately diametrically placed in the machine. The proportion of beam on to each target can be changed predictably by varying the radius of one of the targets, without changing the over-all targetting efficiency.

The foil activation measurements indicate that about 68% of the circulating beam as measured on the induction electrodes is hitting the target. This will be investigated further.

9. COMBINATIONS OF TARGET SPILLS

The targets at Nimrod may be fully flipped in about 150 msecs. This enables different types of spill with an interval between of about 50 msec to be obtained during one machine burst. Some examples of combinations of spill used operationally are:

a) Noise spill on current rise, bubble chamber spill, flat-top spill with each spill on to a different target.

b) Two bubble chamber spills about 400 msec apart, with noise spill or multiple phase shift spill in between (Figure 6).

c) Different combinations of spill on different machine bursts within a cycle of nine bursts.

Acknowledgments

The techniques described were developed primarily by the authors whose appreciation is expressed to the many people in the Nimrod Division who have put much effort into the hardware to enable the techniques to be tried and used in operation.

REFERENCES

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(5) J. W. Burren: AERE - M 521 (1959).
(6) J. B. Cumming: Ann. Rev. Nuclear Sci. *13*, 26 (1963).

DISCUSSION

BLEWETT M. H.: What is targeting efficiency with fast spill using the r.f. phase-shifter. Is it better or worse than normal targeting?

GRAY: It is the same.

BERNARDINI C.: Could you give the frequency of the phase oscillations in Nimrod?

GRAY: It varies from 5 kHz to 2 kHz.

RATNER: How long does it take to spill the entire beam for the bubble chamber with phase change targeting?

GRAY: During current rise, the time depends on dB/dt. Under our normal conditions it is about 0.5 msec. During flat-top it is about the same.