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APPLICATION OF FFAG PRINCIPLE TO BETATRON ACCELERATION*

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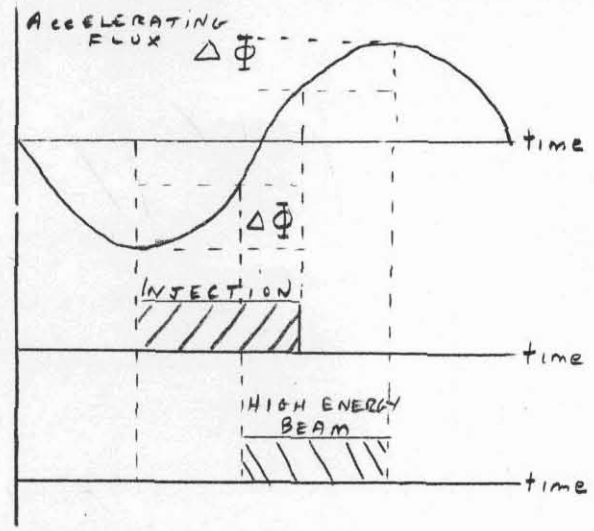
The large momentum spread which can be held by the reversing field and alternating gradient type of fixed field ring magnet described by K. Symon[1] allows a great increase in the acceptance time of injected particles if betatron acceleration is used. The injected particles can be accepted in the D.C. magnet gap at the low energy radius all the time that the central flux is rising; as the particles gain energy, they spiral toward the high field radius. After each particle orbit has linked a certain change in flux it arrives at the target. Charged particles continue to arrive at the target as long as the flux continues to rise above the minimum necessary to bring a particle to full energy (see Figure 1). In contrast to fixed field weak focussing accelerators, the high radial gradient of the FFAG machine allows a hole at the center for the accelerating core.

If the focussing magnetic field is set at a magnitude such that half the flux is needed to accelerate the beam from the low to the high magnetic field region, the duty cycle would approach 25 per cent.



$\Delta\Phi$ = flux change necessary to accelerate a particle to full energy.

FIGURE 1.

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1) K. R. Symon accompanying MURA-6 Report.

The acceptance time per cycle in present day betatrons and electron synchrotrons is about 10^{-7} seconds, while the acceptance time in this new accelerator would be 4×10^{-3} seconds per cycle at 60 cycles per second. Thus there is a factor of 4×10^{4} increase in the injection time. There will probably not be this large increase in beam output because space charge in the early stages of acceleration will be a limiting factor; however, the very large gap possible at the low field region of the magnet provides a large space to fill before the space charge forces are eliminated by the approach to the velocity of light. High energy injection would also raise the limit.

A working test of the FFAG poles is being planned using the 80 Mev betatron at the University of Illinois. Mark I-type poles for this could have the following parameters:

Injection average field $H_i = 25$ gauss

Injection radius $R_i = 25$ cm; $\rho_i = 5$ cm

Final radius $R_o = 35$ cm; $\rho_o = 7$ cm

$$\frac{H_{max}}{H_{inj}} = \frac{10{,}000}{5 \times 25} = 80$$

$C = 5$, $n = \frac{\rho}{H} \frac{dH}{dr} = 2.6$

For $\sigma_1 = 5\pi/6$, $\sigma_2 = \pi/6$, with $H_1' = |H_2'|$

$\psi_1 = 2.0 = \sqrt{n}\,\beta_1$, $\beta_1 = 1.23$

$\psi_2 = 1.34 = \sqrt{n}\,\beta_2$ $\beta_2 = .82$

$N = \frac{2\pi}{(\beta_1 - \beta_2)} = 15$

$E_{max} = 20$ Mev

$\Delta\Phi$ for full acceleration = .12 webers or in 20 cm radius core

$\Delta B = 11{,}000$ gausses

ΔB available $\sim 26{,}000$

Duty cycle approximately 30%

For 60 cycle per second core excitation, the acceleration is rapid enough to cause the orbit to expand on the first turn sufficiently to miss the injector structure (about 1/2 millimeter). A problem of making Mark I poles on the scale described above is the design of coils for the 20 Mev scale of the FFAG magnet.

The low circumferential average of the bending field caused by the segments with reversed fields lowers the energy limit of these betatrons undesireably. Therefore, it is important to develop a uni-directional D.C. field system. Such a focussing field with good momentum compaction is described in the accompanying report on ridged poles but it has not been as fully analyzed as the simpler reversing field type.[2] Applied to the 300 Mev betatron, it would allow very high intensities and long pulses at the meson production threshold.

The large acceptance time might make possible beams of positrons originating from radioactive material near the inner walls of the donut.

2) MURA (Mark V)