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# PLACEMENT OF THE SYNCHROTRON BEAM ON AN INTERNAL TARGET. II.

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## ABSTRACT

An alternate method of placing the internal beam of the synchrotron on an internal target in a very short time, one microsecond, is proposed. An earlier study (UCRL-2543) considers the radial blow-up of the beam by the azimuthal variation of the magnetic field of the synchrotron at the radial field gradient specified by $n = 0.75$. The present system proposes the application of a radiofrequency electric field resonant with the radial oscillations producing blow-up at the unmodified field gradient specified by $n = 0.67$. The axial and radial oscillation frequencies are not commensurable; thus resonance blow-up is avoided in the axial direction.

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## INTRODUCTION

The ability to place the circulating beam on an internal target of the synchrotron in one microsecond will increase the experimental possibilities for it. Under the present operating conditions, the beam strikes the target at an inner radius by slowly spiraling inward from the orbit it has attained at the end of the acceleration cycle. The inward spiraling occurs because the particles lose energy by radiation in an almost constant magnetic field. The major portion of the beam strikes the target in a manner to give a bremsstrahlung spectrum from 15 to 25 microseconds in duration. A small portion of the beam strikes the target prior to and following the main portion so that radiation is observed over about 80 microseconds. Report No. UCRL-2543 with the same title, part I, includes details of the synchrotron applying to this problem.

The reduction of the bremsstrahlung duration to one microsecond with no subsequent radiation will permit time-of-flight and decay-in-flight experiments and reduce the background radiation from the small portion of the beam.

Attempts to deflect the beam a fraction of an inch onto the target by a direct pulsed electric field were unsuccessful because of inability to hold the required voltage. The application of a radiofrequency voltage resonant with the radial oscillation frequency will induce a rapid increase of oscillation amplitude and the precession will carry the particles onto the target. The requirements to accomplish this are determined below.

## PARTICLE MOTION IN THE PRESENCE OF A PERIODIC DISTURBANCE

The equations of motion of the particles undergoing free oscillations are:

$$d^2\rho/dt^2 + (1 - n)\ \omega_o^{\ 2}\rho = 0,$$

$$d^2z/dt^2 + n\ \omega_o^{\ 2}\ z = 0,$$

where $\rho$ and $z$ are the displacements from the equilibrium orbit, $n$ is $-\frac{r}{B}\frac{\partial B}{\partial r}$ and defines the radial field gradient, $\omega_o$ is the angular frequency of the particle in the synchrotron, and $t$ is time.

The relation between the radial and axial oscillation angular frequencies and $\omega_o$ are:

$$\omega_r = \sqrt{1 - n}\quad \omega_o,$$
$$\omega_z = \sqrt{n}\quad \omega_o.$$

In the Berkeley synchrotron the value of $n$ is 0.67 and remains unchanged. Likewise $\omega_o$ remains practically unchanged. As the particles travel at almost the velocity of light, $\omega_o$ is given by

$$\omega_o = v/r = c/r.$$

The equilibrium orbit is very close to one meter, giving $\omega_o$ = 300 megaradians per second. Thus $f_o$ = 47.8 megacycles per second.

The change in $\omega_o$ occurring as the particles spiral inward is very small because of the small change in the radius. The maximum change in $\omega_o$ is about 0.5 percent.

The radial and axial frequencies are related by

$$\frac{f_r}{f_z} = \frac{\omega_r}{\omega_z} = \sqrt{\frac{1 - n}{n}}\ .$$

For $n = 2/3$, $f_r/f_z = \sqrt{1/2} = 0.707$, which is not commensurable.

The radial oscillation frequency is

$$f_r = \sqrt{1 - n} \; f_o$$
$$= 27.6 \text{ megacycles per second.}$$

Now we shall consider the differential equations when there is a forcing term present.

$$d^2 \rho/dt^2 + (1 - n)\, \omega_o^2\, \rho = K \sin \sqrt{(1 - n)}\; \omega_o t \;,$$

$$d^2 z/dt^2 + n\, \omega_o^2\, z = K \sin \sqrt{1 - n}\; \omega_o t \;.$$

The solutions of these equations are:

$$\rho = A_r \sin \omega_r t + B_r \cos \omega_r t - \frac{Kt}{2\omega_r} \cos \omega_r t,$$

$$z = A_z \sin \omega_z t + B_z \cos \omega_z t + \frac{K}{\omega_z^2 - \omega_r^2} \sin \omega_r t \;.$$

In the $z$ solution, the third term on the right has a constant amplitude but a different frequency than the free oscillations. This may be considered as a modulation of the free-oscillations amplitude.

In the $\rho$ solution, the linear increase of the amplitude of the coefficient of the third term on the right in time is observed. This amplitude increase will predominate the situation and large oscillations will cause the particles to strike the target.

## RADIOFREQUENCY FIELD REQUIRED FOR RAPID BLOW-UP

The periodic force on the particle in the synchrotron occurs only in the region of the deflecting plates. Let their length along the path be $\ell$. The force is $e\epsilon$ where $e$ is the electronic charge and $\epsilon$ is the electric field gradient from the deflector.

From the solution of the radial equation, setting $A_r = 0$, we obtain

$$\rho = \left[ B_o - \frac{Kt}{2\omega_o \sqrt{1 - n}} \right] \cos \sqrt{1 - n} \quad \omega_o t \quad .$$

At $t = 0$, let $\rho = B_o$, while at $t = t$, let $B_o - \frac{Kt}{2\omega_o \sqrt{1 - n}} = B$ where $B >> B_o$, and let $B = xB_o$, thus considering the magnitudes

$$\left| \frac{Kt}{2\omega_o \sqrt{1 - n}} \right| = \left| (x - 1) B_o \right| ,$$

thus

$$K = \frac{2(x - 1) B_o \quad \omega_o \sqrt{1 - n}}{t} \quad .$$

Since $K = \frac{e\epsilon}{m} = \frac{e\epsilon \, c^2}{mc^2} = \frac{e\epsilon \, c^2}{E}$, we obtain

$$e\epsilon = \frac{2\omega_o \sqrt{1 - n} \quad (x - 1) B_o \quad E}{c^2 t} \quad .$$

This is the total force normal to the synchronous orbit required to give an increase in amplitude of $(x - 1)$ in time $t$.

Since the length of the deflector is $\ell$, and the electrons are perturbed only in this region, the field gradient must be increased to make the net force equal the value computed above. This ratio is given by

$$\frac{2 \pi R}{\ell}$$

where R is the synchronous radius of the electrons.

Thus the required electric field gradient in the deflector is

$$e\epsilon = \frac{2\omega_o \sqrt{1-n}\ (x-1)\ B_o\ E}{c^2 t} \cdot \frac{2\pi R}{\ell} .$$

As an example, for 350-Mev electrons, $E = 3.5 \times 10^8$ ev, $x = 500$, $\omega_o = 3 \times 10^8$ rad/sec, $R = 1$ meter, $\ell = 25$ cm, $t = 10^{-6}$ sec, $n = 2/3$

$$e\epsilon = 1.7 \times 10^6\ B_o \text{ ev/cm}$$

In the synchrotron the value of $B_o$ at the time a perturbation would be applied is small, about 0.1 cm, owing to the damping observed. The amplification factor x must be smaller for larger $B_o$; thus the value computed in the example is certainly higher than required. The product of gradient and deflector length below is believed to be sufficient to cause the beam destruction in one microsecond in the Berkeley synchrotron.

$$e\epsilon\ell = 1.7 \times 10^5 \qquad \text{electron volts cm/cm}$$

One notes the compensation between $B_o$ and x required to produce a given amplitude; thus the final amplitude is independent of the initial amplitude and is a measure of the energy supplied to the electrons in the radial direction.

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