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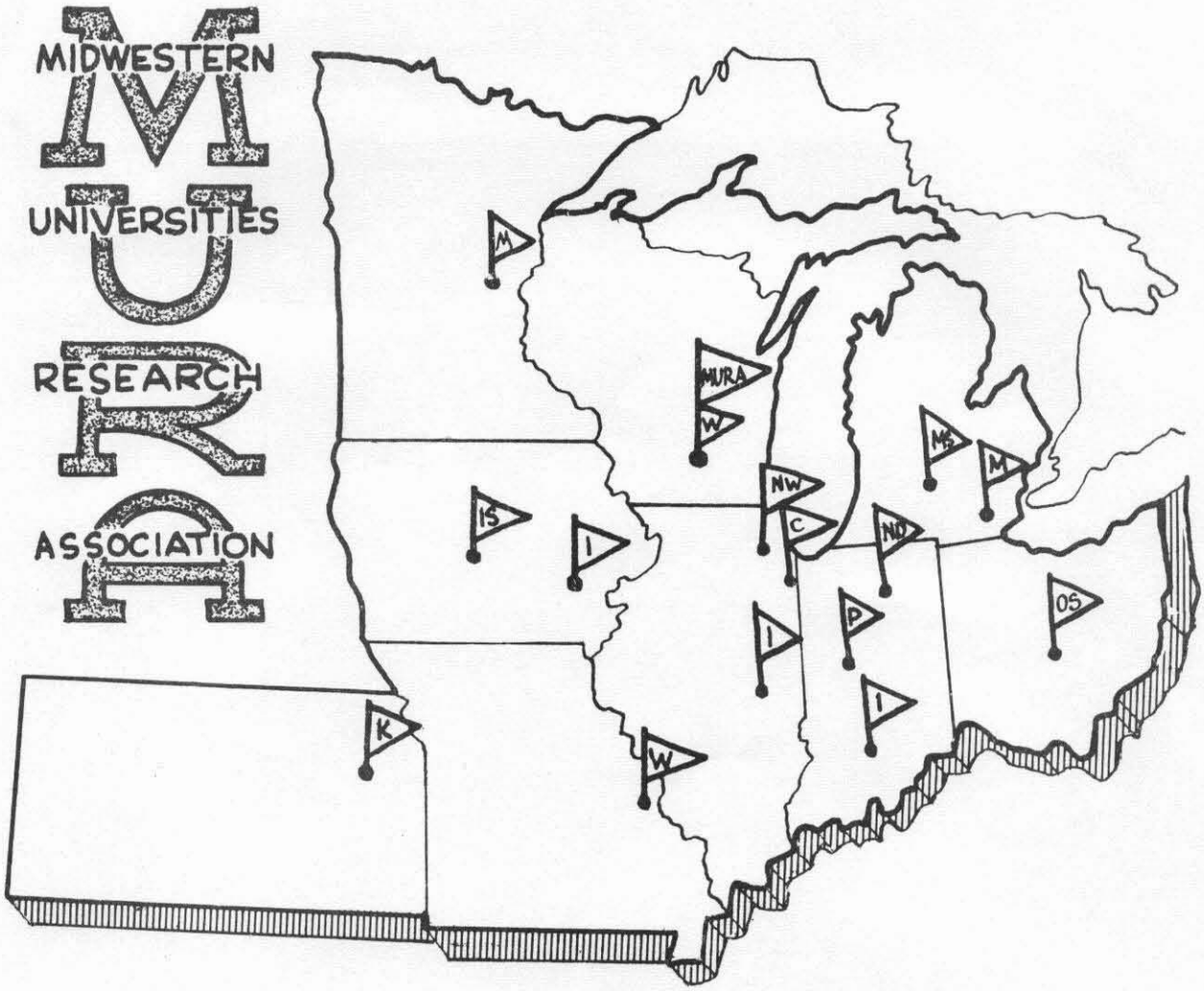

A BETATRON BEAM STACKING PROCESS AND A-SYNCHRONOUS ACCELERATION WITHOUT A LARGE BETATRON CORE*

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A BETATRON BEAM STACKING PROCESS AND A-SYNCHRONOUS ACCELERATION WITHOUT A LARGE BETATRON CORE*

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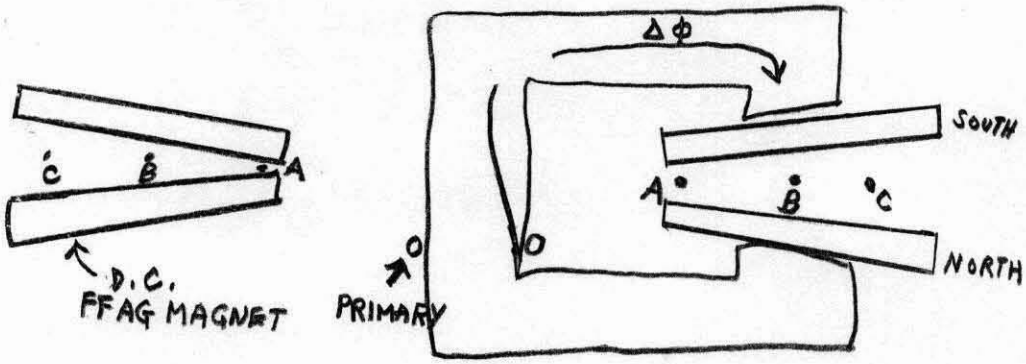
It would be highly desirable to be able to use betatron action for acceleration, since no synchronization is necessary; and it is also attractive to explore how to stack a beam by betatron action for purposes of achieving very high circulating currents.

A-synchronous acceleration or stacking by β-tron flux might be achieved by returning the accelerating flux through the orbit focussing region. Orbit "A" is accelerated by the whole flux, ϕ



until it is in the return path of ϕ in the D. C. magnet. Gradually

* The ideas mentioned here have also had previous consideration by T. Ohkawa.

it comes to rest at the radius of B when the flux ϕ reaches its maximum, provided the D. C. magnet has positive momentum compaction. If the point B is near the outside edge of the flux return path at C, then it cannot be further accelerated no matter how large ϕ becomes and subsequently injected particles will stack at a slightly smaller radius near C. This is not the case for a negative momentum compaction magnet.

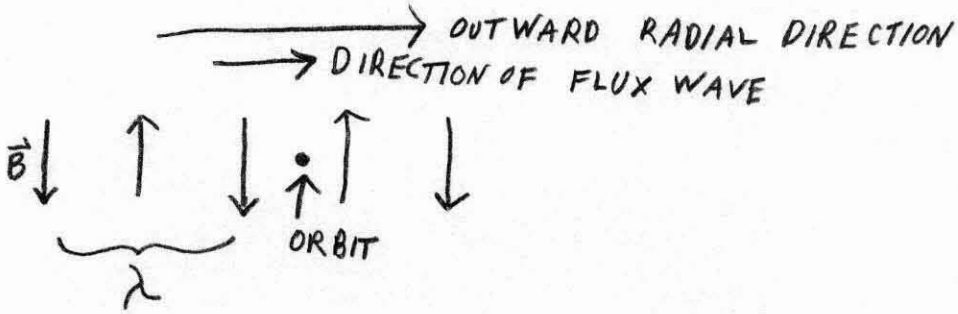
Since the amount of flux change $\Delta\phi_{TOTAL}$ to accelerate a particle to C is of the order of $2\pi R^2\bar{H}_c$, where $\bar{H}_c$ is the average field around the circumference at radius C, we can see that the return accelerating flux density passing through the gap at the orbit is similar in magnitude to the flux density of the focussing field. Thus the question arises of how to mix this return accelerating flux density with the focussing field so that the focussing and stability are preserved and so that stacking at approximately one radius can occur.

If the flux is returned across the gap by coupling to the same pole pieces which are used for focussing, then it has an r^k dependence and there is no point C at the edge of the return flux. If the flux is returned by separate pole pieces in the straight sections between the FFAG poles, then it will contribute to the focussing except at the instant when ϕ is zero. (It could have started from a negative bias.) At that time the point C can be reached with no focussing effect of ϕ. It is not clear that particles injected over a period of time to build up an intense circulating beam can be accelerated by some combination of this flux and an FFAG field. If we could inject and stack for a quarter of a cycle at 60 cycles per second, and if we injected at the rate

of 10 milliamperes of electrons, we would stack 4.0×10^{-5} coulombs which circulate around the orbit once every 5×10^{-9} seconds at relativistic energies, thereby producing 8,000 amperes.

This feature of returning the flux used in betatron acceleration through the orbital focussing annular region can be used for acceleration without a full-sized betatron core in the following way. Imagine that the particle reached orbit B by induction acceleration. If we now want to decrease the accelerating flux back to the starting point, we would ordinarily remove all of the energy we had already given to the particle. However, if we control the region of the gap from which flux is removed - particularly if we remove flux from the region between A and B first, then we remove no energy from the particle while that first diminution of flux is taking place. The flux contained at radii greater than the radius of B will decelerate the particle part way when it is removed. This process can be repeated with a net acceleration each time.

This process is equivalent to causing an alternating flux wave with a radially outward velocity to pass over the particle's orbit.



While the downward directed lines of force are passing over the orbit, there is an accelerating electric field normal to $\vec{B}$ and parallel to the orbit. The orbit takes on a greater radius (positive momentum compaction) and stays in contact with the accelerating field until the region of upwardly directed lines of force overtakes the orbit. While in this reverse field region, the particle loses energy and its radius moves inward. If V is the radially outward phase velocity of the flux wave and if v is the rate of change of radius of the orbit under the influence of the induced electric field, then the particle is in the accelerating field for a time $\frac{\lambda}{2}\frac{1}{(V-v)}$ and in the decelerating field for a time $\frac{\lambda}{2}\frac{1}{(V+v)}$. Thus there is a net acceleration of the particle and the ratio of energy gain to loss is $\frac{V+v}{V-v}$. It is evident that for most efficient use of the accelerating flux we should make v as close to V as possible. In other words, the outward velocity of the orbital position should be a good fraction of the flux wave velocity. If v = V, we accelerate all the way out but the magnitude of the accelerating flux density is of the same order as the magnitude of the average focussing field. If $V > v$, the acceleration is peristaltic with the orbital radius increasing and decreasing, but being generally pushed out along a radius. If V = c, the velocity of light, we have a transverse electromagnetic wave with the Poynting vector directed outwardly, thereby producing acceleration by radiation pressure.

These traveling flux waves could be produced either in R. F. wave guides passing radiation across the orbit or by polyphase stators wound like induction motors but arranged linearly above

and below the orbit. The amplitude of the flux wave could be made to vary with radius and to decrease to zero for purpose of stacking, or to increase like r^k to act as the reverse field segment of a Mark I FFAG.

The efficiency of using the accelerating part of the flux wave can be increased greatly by having magnetic bumps of the same polarity in the bending field placed about one fourth of a betatron oscillation wave length to each side of the accelerating element, so that the orbit would be bent to follow the outward motion of the accelerating field for a while and then to snap back quickly through the decelerating region and into the next oncoming accelerating region. These bumps could travel outwardly with the same speed as the accelerating flux wave, but then the bumps themselves would produce acceleration with an unimproved efficiency. However, if the deflecting bumps are stationary but located so that with the accelerating wave of the proper strength and velocity the bumps deflect the outwardly moving orbit always into the accelerating region, then we do not get accelerating effects from the bumps.