MURA-465
TID-4500 (15th Edition)
UC-28

MIDWESTERN UNIVERSITIES RESEARCH ASSOCIATION*

2203 University Avenue, Madison, Wisconsin

ULTRA HIGH ENERGY SYNCHROTRONS

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June 10, 1959

ABSTRACT

A discussion is given of the technical feasibility and economic scale of pulsed AG synchrotrons with maximum energies of 100 and 300 Bev. The 100 Bev machine is similar to a scaled Brookhaven (30 Bev)AG synchrotron, while the 300 Bev machine consists of two synchrotrons in cascade, the beam being transferred to a small aperture second stage at 10 Bev. It is concluded that the cost of either the 100 or 300 Bev is of the same order as a 10 Bev high-intensity FFAG accelerator.

*AEC Research and Development Report. Research supported by the Atomic Energy Commission, Contract No. AEC AT(11-1)-384

Most of the discussions of this conference have concerned high-intensity proton accelerators with energies near 10 Bev. It is also possible that a desirable "next-step" in the development of accelerators could be in the direction of higher energies--energies significantly in excess of the 30 Bev machines now nearing completion.

An attempt has been made to investigate briefly the technical feasibility and the economic scale of pulsed AG synchrotrons with maximum energies from 100 to 300 Bev. Two possible configurations have been considered: a 100 Bev AGS patterned closely after the existing 30 Bev designs, and a 300 Bev synchrotron of a more radical design. The latter machine would give interaction energies equivalent to 12 Bev colliding beams, and interaction rates larger than those contemplated in current colliding beam proposals. The cost of both machines is believed to be comparable to that of a 10 Bev FFAG synchrotron. The cost estimate of the 100 Bev machine is based on a straightforward scaling of the Brookhaven costs for the AGS and is, therefore, reasonably sound. The cost estimate for the 300 Bev configuration is much less sound, but has, for this reason, been made generously and is believed to be as reasonable an estimate as can be given quickly for a concept which has some novel aspects.

The 100 Bev Machine

The 100 Bev machine would consist of a magnet with a cross section identical to that of the Brookhaven AGS, and a radius scaled up by a factor of 3. The injector would be a linac of the Brookhaven design increased to an energy of 200 Mev (four times that of the existing design). The magnetic induction

at injection would be only 2/3 that of the AGS, and the relative aperture would be 1/3. The construction of the magnet would, therefore, be more critical than the original specifications of the AGS, but experience to date indicates that the AGS aperture is generous, and future experience should make it feasible to maintain the required tolerances, with at most, some decrease in the maximum attainable intensities.

The time cycle of the magnet would be one-half as fast as that of the AGS--an acceleration time of 2 seconds. One would contemplate reaching intensities of 10^{12} particles per pulse.

Table I gives a cost estimate for the suggested 100 Bev machine, together with the approximately known costs for the corresponding items for the AGS. The numbers were obtained in the following way:

Magnet. All magnet costs were increased by a factor of 3 except the design costs, since it intended to adopt directly the AGS design.

Injector. Double the cost, since four times the energy uses much of same design and components.

Vacuum. Triple the cost, taken proportional to circumference.

R. F. This is the most difficult to extrapolate; the F-M range will be a little higher and the volts per turn will be 4.5 times higher, the volts per cavity would, however, be only 1.5 times higher; take a factor of 4 (but investigate later).

Controls and Design. A guess.

Buildings. Tunnels are taken at three times the AGS (including the injector), other items increased by a nominal amount.

TABLE I

Cost Estimate for 100 Bev Synchrotron

Item	100 Bev (Thousands)
Magnet	
Core	$ 9,000
Coil	6,000
Power	3,000
Miscellaneous	1,000
Design	1,000
	$20,000
Other Components	
Injector	$ 3,000
Vacuum	2,500
R. F.	3,000
Controls	2,000
Design	1,000
	$11,500
Building	
Tunnels (incl. inj.)	$10,500
Experimental	3,000
Offices & Labs	2,000
Architects	2,000
	$17,500
Salaries	$ 8,000
Experimental Equipment	$ 5,000
TOTAL	$62,000
Inflation, Etc.	$15,000
	$77,000

Salaries. It is proposed that the construction schedule be set at 10 years. The personnel requirements would then be the same as the AGS. Salaries are up by 1.5, but note that offices, etc. are not.

Total Cost. $77,000,000 (± 10%) (and the - is real!).

The 300 Bev Machine

The 300 Bev machine would consist of a linac plus two synchrotron stages in cascade. For such a configuration, the aperture of the high-energy stage need only be large enough to accommodate the oscillations remaining after the adiabatic damping of the first stage. If this is done, the total energy stored in the two magnets is a minumum when the momentum at which particles are transferred from Stage 1 to Stage 2 is the geometric mean of the final momentum and the initial momentum of Stage 1. The same criterion gives equal stored energies for the two stages, and the same stored energy can be used for the two stages in succession.

The optimum criterion cited above gives an exceedingly small aperture for the second stage. It is, therefore, proposed to increase the stored energy of Stage 2 to twice that of Stage 1. The cost of the magnet is then more in keeping with that of the structure which houses it.

The parameters proposed for the 300 Bev machine are given in Table II. The first stage synchrotron is a copy of the AGS, with a 1/3 reduction in radius only. It presents no problems.

The guide field proposed for Stage 2 has a small aperture and a large value of ν. It is not considered that suitable orbits would be obtained with

TABLE II

Parameters of the 300 Bev Accelerator

	Stage I	Stage II
Injection Energy	50 Mev (ρ = 0.3 Bev/c)	10 Bev
Final Energy	10 Bev	300 Bev
Injection Field	300 gauss	600 gauss
Radius	30 meters	1,000 meters
Aperture Radial Vertical	 14 cm 6 cm	 5 cm 1.5 cm
Stored Energy	1/3 x AGS	2/3 x AGS
Focusing ν λ	 $\approx$ 3 $\approx$60 meters	 $\approx$ 100 $\approx$ 60 meters
Acceleration Time	1 sec	1 sec
Volts per turn	$\approx$ 7 Kev	6 Mev
$\Delta f/f$	2/3	1/200

tolerances which could be met in the initial construction. It seems, instead, more reasonable to tune the guide field on the basis of the actual orbits obtained. With the proposed high injection fields, and with the available data on the reproducibility of magnetic cycling it appears that such a tuning procedure is feasible. The tuning would be both for the closed orbit and for the operating point. It is to be noted that to maintain its tune the magnet need be reproducible to about 1 part in 1000. Slow drifts in tune could be accommodated by automatic or manual adjustments. Note too that the small size of the magnet will allow assembly on a common rigid frame of large azimuthal segments of the magnet which segments will then be held in close relative alignment. Space charge detuning is, of course, no problem.

The R. F. system of Stage 2 presents some problems. The most serious is probably the required beam radius tolerance of approximately 1 in 10^5. But this is over a frequency change of only one part in 200. Beam control methods will certainly be required near the transition energy. The increase in phase oscillation at transition should not be serious.

The required voltage is to be obtained by a system of high Q cavities, modulated the required 0.5% by mechanical deformation. The required total cavity voltage per turn is about 12 Mev. It would appear possible to get such voltages by the methods of the Cambridge Accelerator group, with R. F. powers of about 500 KW. Their experience also provides a cost estimate for such a system.

The problem of beam transfer has not been examined in detail. It is presumed that the methods of the storage ring designs can be adopted. The

most stringent requirement appears to be that the transfer must occur at the proper momentum within one or two parts in 10^3. This does not appear to be impossible. Angular errors of transfer need only be comparable to the free oscillation angles at the time of transfer as in the storage ring schemes.

The cost estimates for the 300 Bev machine are given in Table III. For Stage I (the 10 Bev accelerator) the values are taken to be 0.3 to 0.4 of the AGS figures. The stage 2 figures are estimates based on mass of iron, power required and building space required, all derived from the AGS figures by suitable ratios. The R.F. system costs are based on the Cambridge Accelerator.

The total estimate of $75 million would indicate that further study of such a proposal is warranted.

The preparation of this material was helped by discussions with E. D. Courant, M. H. Blewett, and K. M. Robinson.

TABLE III

Cost Estimate for 300 Bev Machine

Item	300 Bev	
	Stage I (Thousands)	Stage II (Thousands)
Magnet		
Core	$ 1,000	$ 2,000
Coil	1,000	2,000
Power	500	1,000
Miscellaneous	500	1,000
Design	500	1,000
	$ 3,500	$ 7,000
Other Components		
Injector	$ 2,500	$ --
Vacuum	300	4,000
R. F.	300	3,000
Controls	300	3,000
Design	400	1,700
	$ 3,800	$11,700
Building		
Tunnels	$ 1,000	$ 9,000
Experimental	--	5,000
Offices & Labs	--	2,000
Architects	500	2,000
	$ 1,500	$18,000
Salaries, Wages, Etc.	$ 2,000	$ 8,000
Experimental Equipment	$ --	$ 5,000
TOTAL	$10,800	$49,700
		10,800
Inflation, Etc.		14,500
GRAND TOTAL		$75,000