MIDWESTERN UNIVERSITIES RESEARCH ASSOCIATION*

2203 University Avenue, Madison, Wisconsin

COST ESTIMATE COMPARISON OF THREE MULTI-BEV FFAG ACCELERATORS

Kent M. Terwilliger
University of Michigan

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ABSTRACT

This report compares the costs of the MURA proposal accelerator, a 15 Bev two-way radial sector type, with a similar 10 Bev machine, and a 10 Bev one-way spiral sector accelerator.

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INTRODUCTION

This report compares the costs of the MURA proposal accelerator, a 15 Bev two-way radial sector type, with a similar 10 Bev machine, and a 10 Bev one-way spiral sector accelerator. The Brobeck and Associates cost analysis of the 15 Bev machine has been assumed for this comparison. The costs of the others were then roughly estimated by comparison with the 15 Bev machine. Total machine costs are given, including experimental areas and starting experimental equipment.

The two radial sector machines are identical in every respect save energy and size; both are two-way and require high vacuum and efficient rf stacking. The 10 Bev spiral machine is one-way and requires only a standard vacuum and a simpler rf acceleration procedure.

Table I is a summary of the relative costs for the three accelerators. Table II lists the major design parameters assumed or computed. Table III lists the cost dependences assumed in making the comparison. In the table the dependence is usually expressed in terms of the ratio of machine radii, R. The 10 Bev Mark I costs were obtained directly from the 15 Bev Mark I Brobeck estimates; the 10 Bev Mark V costs were then obtained from the 10 Bev Mark I results.

TABLE I

Summary

FFAG Accelerator Cost Estimate Comparison (in thousands)

	15 Bev Mark I Two-way	10 Bev Mark I Two-way	10 Bev Mark V One-way
A. Site, Utilities, DC Supplies, Buildings and Tunnels	Brobeck Estimate		
Engineering, Design & Supervision	$ 2,517	$ 1,250	$ 980
Site Development	435	300	120
Plant Utilities	973	670	420
Accelerator Utilities	8,745	3,940	3,130
Accelerator Tunnel & Beam Vaults	19,635	9,391	6,877
Buildings	3,582	2,660	2,660
Magnet and RF System DC Power	10,835	5,020	4,035
	$ 46,722	$ 23,231	$ 18,222
B. Accelerator Construction			
Engineering, Design & Supervision	$ 7,800	$ 3,420	$ 2,500
Magnet Core	31,340	10,330	9,300
Magnet Coils	24,051	11,100	9,450
Magnet Accessories & Miscellaneous	2,984	2,060	830
Vacuum Tanks & Accessories	12,807	6,090	2,350
Vacuum Pumping System	1,763	840	450
Injector	2,212	2,212	2,212
Radio Frequency System	12,615	6,000	3,200
Auxiliary Magnets & Power Supplies	2,211	1,050	1,050
Instruments and Controls	671	463	290
	$ 98,454	$ 43,565	$ 31,632
C. Accelerator Development	$ 13,160	$ 9,000	$ 6,750
Total 1	$158,336	$ 75,796	$ 56,604
D. Project Administration & Services	$ 2,900	$ 1,390	$ 1,035
E. Construction Management	$ 3,708	$ 1,780	$ 1,330
F. Research and Operating Equipment	$ 9,200	$ 4,370	$ 4,370
Total 2	$174,144	$ 83,336	$ 63,339
G. Escalation	$ 26,619	$ 12,700	$ 9,670
H. Contingency	$ 24,312	$ 11,620	$ 8,840
GRAND TOTAL	$225,075	$107,656	$ 81,849

TABLE II

Machine Parameters

Energy	15 Bev Mark I Two-way	10 Bev Mark I Two-way	10 Bev Mark V One-way
Radius	180 meters	124 meters	50 meters
C	5.8	6.0	2.0
H max on Eq. orbit	17,000 gauss	17,500	14,400
N	62	62	30
k	212	212	53
$\tan\gamma$	-	-	.1
λ_r	-	-	1.05 meter
ν_x	24.75	24.75	8.4
ν_z	4.3	4.3	7.2
Stability limits (in radius units)			
x	1.3×10^{-3}	1.3×10^{-3}	1.0×10^{-3}
z	1.0×10^{-3}	1.0×10^{-3}	0.7×10^{-3}
Magnet vert. gap (min.)	15 cm	15 cm	15 cm
T inj	50 Mev	50 Mev	50 Mev
$\frac{P_f}{P_i}$	50	35	35
$\frac{r_f - r_i}{r} = \frac{\Delta r}{r}$ (mom. difference)	.0187	.0169	.068
Δr (mom. difference)	3.35 meters	2.03 m	3.4 m
Δr (vac chamber)	4.9 meters	3.25 m	4 m
Iron	60,100 tons	20,000 tons	13,300 tons
Current density	270 a/cm^2	270 a/cm^2	270 a/cm^2
Copper	3,000 tons	1,330 tons	1,140 tons
Main magnet power	45 MW	20 MW	17 MW
RF power (peak)	9 MW	4.3 MW	2.3 MW

TABLE III

FFAG Accelerator Cost Estimate Comparison
Including Assumed Dependences

A. Site, Utilities, DC Supplies, Buildings and Tunnels	15 Bev Mark I Two-way (Brobeck Estimate) Cost	10 Bev Mark I Two-way Dependence (Relative to 15 Bev Mark I $R=\frac{124}{180}=.69$)	Cost	10 Bev Mark V One-way Dependence (Relative to 10 Bev Mark I $R=\frac{50}{124}=.403$)	Cost
Engineering, Design & Supervision	$ 2,517	Rest of A	$ 1,250	Rest of A	$ 980
Site Development	435	R	300	R	120
Plant Utilities	973	R	670	$R^{1/2}$	420
Accelerator Utilities	8,745	24.3/54(1)	3,940	19.3/24.3	3,130
Accelerator Tunnel & Beam Vaults					
Excavation - Earth	209	R^2	99	$\frac{4}{3}R$(2)	53
Excavation - Rock	754	R^2	360	$\frac{4}{3}R$	192
Tunnel, Including Foundations	4,450	R^2	2,110	$\frac{4}{3}R$	1,120
Colliding Beam Vaults (2)	2,761	R^2	1,310	0	0
Single Beam Vaults (4)	5,142	R^2	2,440	1	2,440
Cranes	2,547	R^2	1,210	1	1,210
Service Area	263	R^2	125	1	125
Injector Area	147	1	147	1	147
Shielding - Concrete	2,814	R^2	1,330	1	1,330
Shielding - Earth	548	R^2	260	1	260
Buildings	3,582	R	2,660	1	2,660
Magnet and RF System DC Power					
Magnet DC Power Supply & Distribution	5,653	Tons Cu $\frac{1330}{3000}$	2,500	Tons Cu $\frac{1140}{1330}$	2,120
High Voltage DC Power Supply & Distribution for RF System	2,550	R^2	1,270	$\frac{4}{3}R$	665
Experimental & Auxiliary Magnet Power Supply	2,632	R^2	1,250	1	1,250
	46,722		23,231		18,222

TABLE III (Continued)

B. Accelerator Construction	15 Bev Mark I Two-way Cost	10 Bev Mark I Two-way Dependence	10 Bev Mark I Two-way Cost	10 Bev Mark V One-way Dependence	10 Bev Mark V One-way Cost
Engineering, Design & Supervision	$ 7,800	Rest of B	$ 3,420	Rest of B	$ 2,500
Magnet Core	31,340	$R^3 = \frac{20,000}{60,100}$ (3)	10,330	13,300	9,300
Magnet Coils	24,051	$\frac{2}{3} R = \frac{1330}{3000}$ (5) Tons Cu	11,100	$\frac{1140}{1330}$ Tons Cu	9,450
Magnet Accessories & Miscellaneous	2,984	R	2,060	R	830
Vacuum Tanks & Accessories	12,807	R^2	6,090	$\frac{4}{3}$ R x .72 (6)	2,350
Vacuum Pumping System	1,763	R^2	840	$\frac{4}{3}$ R	450
Injector	2,212	1	2,212	1	2,212
Radio Frequency System	12,615	R^2	6,000	$\frac{4}{3}$ R	3,200
Auxiliary Magnets & Power Supplies	2,211	R^2	1,050	1	1,050
Instruments and Controls	671	R	463	$R^{1/2}$	290
	98,454		43,565		31,632
C. Accelerator Development	13,160	R	9,000	$\frac{3}{4}$ (7)	6,750
Total 1	158,336		75,796		56,604
D. Project Administration & Services	2,900	Ratio of D to Total 1	1,390	Ratio of D to Total 1	1,035
E. Construction Management	3,708	Ratio of E to Total 1	1,780	Ratio of E to Total 1	1,330
F. Research & Operating Equipment	9,200	R^2	4,370	1	1,370
Total 2	174,144		83,336		63,339
G. Escalation	26,619	Ratio of G to Total 2	12,700	Ratio of G to Total 2	9,670
H. Contingency	24,312	Ratio of H to Total 2	11,620	Ratio of H to Total 2	8,840
GRAND TOTAL	$225,075		$107,656		$ 81,849

Footnotes as follows: (1) ~power ratio, (2) 4/3 from $\Delta r_V / \Delta r_I \cong 4/3$, (3) Iron at $520/ton, (4) Tons at $700/ton, (5) 2/3 from winding in three magnet units, (6) No inner liner for high vacuum, (7) No high vacuum, easier RF.

TABLE IV
BEAM CURRENT ESTIMATES FOR THREE FFAG ACCELERATORS

	15 Bev Mk I	10 Bev Mk I	10 Bev Mk V
Amplitude Stability Limit (in r units)	$\pm 10^{-3}$	$\pm 10^{-3}$	$\pm .7 \times 10^{-3}$
I, Injection space charge limit. Tube above amplitude.	1 amp	1 amp	1 amp
I, Injection with RF on (F = 1/4). Requires 50 turns at 5 ma	.25 a	.25 a	.25 a
Phase Space: No. of inj. turns possible with 50 Mev linac — x	600	400	40
z	100	70	15
Protons/pulse	1.7×10^{13}	1.2×10^{13}	5×10^{12}
I, Average output at 10 pulses/sec	28 μa	19 μa	8 μa
Current Densities For Colliding Beams			(Assume Storage Ring with approx. same parameters as above Mk V.) ↓
J at full energy for one pulse, space charge limited at injection	36 ma/cm^2	52 ma/cm^2	57 ma/cm^2
$\frac{\Delta r}{r}$ for one pulse at full energy, due to 50 kev energy spread at 50 Mev inj.	5×10^{-8}	7×10^{-8}	3×10^{-7}
Number of superpositions allowed (From final radial spread of 10^{-3}, allowing loss factor of 4 in RF density.)	5000	3600	820
J after above superpositions	180 a/cm^2	190 a/cm^2	470 a/cm^2