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MASTER

DEUTERONS FOR ISABELLE

Th. J.M. Sluyters

June 23, 1972

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INTERSECTING STORAGE ACCELERATOR NOTES

DEUTERONS FOR ISABELLE^{*}

Th.J.M. Sluyters

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ABSTRACT

In this write-up we avoid discussing the more complex acceleration of particles heavier than deuterons. The much lower intensities of the highly stripped heavy particles do not seem to pay off for considerable investments in source development, new rf system for the wider required frequency range, new beam diagnostic equipment, etc.

One can assume that the AGS can inject into ISABELLE as much as 10^{12} deuterons per pulse with energies of 32 BeV/c. Limitations of deuteron acceleration in the linac, transfer lines and synchrotron are considered.

Limitations in the Linac

The acceleration and operation mode of deuterons in the AGS depends much on the beam properties of its injector, the 200 MeV linac. In this linac of the Alvarez structure, normal acceleration takes place in the first harmonic. That means that protons progress one cell during one rf period. When we want to accelerate deuterons in this mode, the deuterons have to traverse each cell with the same speed and the final energy of deuterons ($\frac{1}{2}$ mvc) will be 400 MeV (200 MeV/nucleon) instead of the 200 MeV for protons. But then, the rf field has to be increased by two (the power by four!) and the gradients in the quadrupoles also have to be increased by a factor of two (the impulse mv is 2 times larger than for protons).

Another possibility is to inject and accelerate deuterons with half the velocity across each gap so that the impulse remains the same, and therefore the quadrupole field strength and the deuterons are then accelerated in the second harmonic or 4π mode (see Fig. 1).

*Summary of a talk given during the ISABELLE Summer Study.

Fig. 1. A linac cell with the field pattern for protons and for deuterons.

The energy gain across each cell depends on the transit time factor, which is a function of the ratio gap(g)/cell-length(L). In Fig. 1 it is visually shown that for larger g/L ratios the energy gain for deuterons becomes more unfavorable, and this happens in our 200 MeV linac. The energy gain per cell is approximately:

$$W = \bar{E} L_n T \cos \varphi_s \dots\dots (1)$$

in which: $\bar{E}$ = the mean accelerating field

L_n = length of cell n

φ_s = synchronous phase angle

T = transit-time factor including radial dependence

$$= \frac{\sin m \pi g/L}{mg/L} \times \frac{1}{I_o (k_m a)}$$

with m = 1 for protons and m = 2 for deuterons.

From formula (1) it is clear that if we want the deuteron energy gain per cell to be half the proton gain and $\bar{E}$, L_n , φ_s to remain the same then the transit time factor (T_D) for deuterons has to be close to half or more than the transit time factor (T_H) for protons.

The energy gain for protons and deuterons are compared at the entrance and exit of each tank. See Table I. It is clear that deuterons cannot be accelerated to the final relativistic energy of 80 MeV. The energy gain

TABLE I
(transit time factors for protons and deuterons)

Tank		g/l	a (cm)	$T_{H^+} \times R_{H^+}$	$T_{D^+} \times R_{D^+}$	$\frac{T_{D^+} \times R_{D^+}}{T_{H^+} \times R_{H^+}}$	H ⁺ Energy (MeV)	D ⁺ Energy (MeV)	β Deuteron
T ₁	in	.21	2.0	0.73	0.31	0.42	.75	.37	
	out	.31	2.5	0.83	0.42	0.50	10.42	5	
T ₂	in	.20	3.0	0.87	0.62	0.70	10.42	5	
	out	.31		0.84	0.45	0.53	37.54	18	
T ₃	in	.30	3.0	0.84	0.48	0.57	37.54	18	
	out	.36		0.79	0.33	0.41	66.18	30	
T ₄	in	.37	3.0	0.78	0.30	0.38	66.18	30	
	out	.41		0.74	0.21	0.28	92.55	41.5	0.207
T ₅	in	.37	4.0	0.78	0.30	0.38	92.55	41.5	
	out	.40		0.75	0.23	0.31	116.54	50	0.227
T ₆	in	.40	4.0	0.75	0.23	0.30	116.54	50	
	out	.42		0.73	0.18	0.25	138.98	58	0.245
T ₇	in	.42	4.0	0.73	0.18	0.25	138.98	58	
	out	.44		0.70	0.13	0.18	160.53	66	0.259 (f=1.14Mc)
T ₈	in	.44	4.0	0.07	0.13	0.18	160.53	66	
	out	.46		0.68	0.084	0.12	181.01	73	0.271
T ₉	in	.46	4.0	0.68	0.084	0.12	181.01	73	
	out	.47		0.67	0.061	0.09	200.30	80	0.283

$$T_{H^+} = \frac{\sin \pi a/L}{\pi a/L}$$

$$T_{D^+} = \frac{\sin 2\pi a/L}{2\pi a/L}$$

$$R_{H^+} = \frac{1}{I_0(k_1 a)}$$

$$R_{D^+} = \frac{1}{I_0(k_2 a)}$$

per cell gradually becomes too low to be compensated for by the available rf level. More precise calculations will be carried out.

The following general conclusions seem to be valid:

a) acceleration of deuterons up to 30 MeV will not impose a significant change from the procedures of proton acceleration

b) acceleration of deuterons higher than 30 MeV is limited by the available rf power in each tank.

More precise calculations supported by actual acceleration of deuterons will provide more specific figures.

With this information, I feel confident in obtaining a deuteron beam at the end of the linac with the following parameters:

Energy:	40 MeV
Intensity:	20 - 30 mA
Emittance Area:	3π cm·mrad
ΔE :	?

With the available second preinjector and computerized machine control, it will be possible to quickly switch from protons to deuterons.

A year or so ago we actually accelerated 20 mA deuterons in the first tank up to 5 MeV. How will this lower final energy of 40 MeV of the deuterons affect injection and acceleration in the AGS?

Limitations in the Transfer Channel Linac - AGS

The $\geq 3\pi$ cm·mrad deuteron emittance is too large for loss-less transportation of deuterons in the existing transport channel and injector magnets. A redesign of this channel is required.

Limitation in the AGS

The large emittance of $\geq 3\pi$ cm·mrad will limit the final beam current in the AGS. The lower energy is to our advantage in filling time (13 μ sec/turn). Assuming a 20 mA, 40 MeV deuteron beam, through properly injected turns, an overall efficiency of 20%, we arrive at an accelerated deuteron beam of 10^{12} particles/pulse with an emittance about the same as for protons.

Acceleration of deuterons in the AGS is however more complicated. The frequency range of the cavities in operation next year is 2.3 to 4.8 MHz, compared with the present system of 1.4 - 4.6 MHz. This range is too small to accelerate the 40 MeV deuterons directly in our usual 12th harmonic rf field.

A possible solution is to leave one old rf cavity in the ring and accelerate in the 24th harmonic of this cavity until we reach the lower frequency range (2.3 Mc) of the new system and acceleration continues to the final energy. The disadvantage of this scheme is that we have two different tuning systems. Another solution is to merely accelerate with the new cavities. In this case we start to accelerate in the 36th harmonic up to the end of the frequency range (4.8 Mc), reaching an energy of 476 MeV (see Fig. 2).

Fig. 2. The multiple step acceleration of deuterons in the AGS.

At this time we retune the cavities into the 24th harmonic or 3.2 Mc and again we accelerate to 4.8 Mc reaching an energy of 908 MeV. A final retuning to 2.4 Mc and accelerating in the 12th harmonic mode, will bring the deuterons up to the 32 BeV/c.

The present rf cavities are not properly located for such an operation because there is a π phase shift in between the cavities (for the 12th harmonic) with opposite polarity. However, this problem can be solved by rearranging the cavities, so that most cavities accelerate in the 12th and 36th harmonic and one or two cavities actually accelerate in the 24th harmonic.

Acceleration of deuterons in Dubna and Saclay prove the viability of such an rf scheme. Assuming a loss-less retuning, the final intensity of the AGS can reach the 10^{12} particles per pulse.

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