# A STUDY OF POSSIBLE DEUTERON ACCELERATION

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The acceleration of deuterons in a proton synchrotron may be profitable from the point of view of particle physics. Two classes of experiments suggest themselves:

a) Neutron beams. Deuterons at 30 Bev hitting any target may be expected to undergo stripping reactions a large fraction of the time. This should result in the production of 15 Bev neutron beams with much smaller energy spread and better collimation than is obtainable from proton charge exchange. Such a neutron beam should be a powerful tool for many types of experiments.

b) Deuteron bombardment. Since deuterons have T = 0, J = 1, the bombardment of simple target nuclei with deuterons will single out particular sets of isotopic spin and angular momentum states in a different way from what is possible with other bombarding particles. One experiment of this class, using a separated secondary deuteron beam, is currently on the AGS program. Furthermore, comparison of P-X, N-X and D-X processes may furnish information about the binding forces in the deuteron itself.

The acceleration of deuterons in a proton synchrotron is possible if they are injected with the same momentum at which protons are normally injected, and if the synchrotron rf is then adjusted appropriately. Here the problem of accelerating deuterons in the present proton linear accelerator will be discussed.

Non-relativistic deuterons of a given momentum have half the kinetic energy and half the velocity of protons of the same momentum. Therefore, acceleration should be feasible in the mode where the particle spends two periods of the rf in each unit cell of the linac, rather than one as for protons.

In this mode the transit time factors and the radial dependence of the accelerating voltage are both less favorable than in the proton accelerating mode. But since the required accelerating energy is only half of that needed for protons, deuteron acceleration should be feasible provided the products of transit time factors and radial fall-off factors are not less than half what they are in the proton mode.

These factors have been computed, with the parameters of the BNL linac, for both proton and deuteron modes and for all 124 drift tubes, using the theory as given by L. Smith*. The transit time factor is

$$T = \frac{\sin m\pi g/L}{m\pi g/L}$$

and the radial factor is

$$R = \frac{1}{I_o(K_m a)}$$

where $I_o$ is the imaginary Bessel function, g is the gap length, L the length of a unit cell, a the drift tube bore radius, and $K_m$ is given by equation (12.4) from the aforementioned reference:

$$K_m^{\ 2} = 4\pi^2 \left[ \frac{m^2}{L^2} - \frac{1}{\lambda^2} \right] .$$

Here m = 1 for the proton mode and m = 2 for the deuteron mode.

The computations show, as the results given in Table 1 indicate, that for m = 2 the product RT is at least 60% of its value for m = 1. Therefore,

*L. Smith, Handbuch der Physik, 44, 341-389, Section 12

Table 1

| Drift Tube Number | T x R Mode 1 (P) | T x R Mode 2 (D) | Drift Tube Number | T x R Mode 1 (P) | T x R Mode 2 (D) |
|---|---|---|---|---|---|
| 1 | 0.8250 | 0.4674 | 46 | 0.8652 | 0.5498 |
| 2 | 0.8339 | 0.4855 | 47 | 0.8665 | 0.5528 |
| 3 | 0.8417 | 0.5016 | 48 | 0.8677 | 0.5556 |
| 4 | 0.8486 | 0.5167 | 49 | 0.8689 | 0.5584 |
| 5 | 0.8543 | 0.5291 | 50 | 0.8700 | 0.5609 |
| 6 | 0.8597 | 0.5414 | 51 | 0.8711 | 0.5635 |
| 7 | 0.8642 | 0.5518 | 52 | 0.8721 | 0.5659 |
| 8 | 0.8684 | 0.5616 | 53 | 0.8731 | 0.5683 |
| 9 | 0.8192 | 0.4553 | 54 | 0.8739 | 0.5703 |
| 10 | 0.8257 | 0.4681 | 55 | 0.8749 | 0.5725 |
| 11 | 0.8315 | 0.4794 | 56 | 0.8756 | 0.5743 |
| 12 | 0.8369 | 0.4907 | 57 | 0.8765 | 0.5764 |
| 13 | 0.8417 | 0.5007 | 58 | 0.8772 | 0.5782 |
| 14 | 0.8462 | 0.5104 | 59 | 0.8779 | 0.5798 |
| 15 | 0.8503 | 0.5192 | 60 | 0.8786 | 0.5815 |
| 16 | 0.8540 | 0.5275 | 61 | 0.8793 | 0.5831 |
| 17 | 0.8573 | 0.5347 | 62 | 0.8800 | 0.5847 |
| 18 | 0.8606 | 0.5422 | 63 | 0.8806 | 0.5863 |
| 19 | 0.8253 | 0.4660 | 64 | 0.8811 | 0.5874 |
| 20 | 0.8296 | 0.4747 | 65 | 0.8817 | 0.5888 |
| 21 | 0.8337 | 0.4830 | 66 | 0.8822 | 0.5902 |
| 22 | 0.8375 | 0.4907 | 67 | 0.8827 | 0.5913 |
| 23 | 0.8411 | 0.4982 | 68 | 0.8832 | 0.5926 |
| 24 | 0.8443 | 0.5050 | 69 | 0.8836 | 0.5935 |
| 25 | 0.8473 | 0.5114 | 70 | 0.8841 | 0.5947 |
| 26 | 0.8502 | 0.5178 | 71 | 0.8845 | 0.5956 |
| 27 | 0.8528 | 0.5234 | 72 | 0.8849 | 0.5965 |
| 28 | 0.8554 | 0.5293 | 73 | 0.8839 | 0.5935 |
| 29 | 0.8577 | 0.5344 | 74 | 0.8856 | 0.5982 |
| 30 | 0.8600 | 0.5395 | 75 | 0.8859 | 0.5990 |
| 31 | 0.8621 | 0.5443 | 76 | 0.8863 | 0.5999 |
| 32 | 0.8640 | 0.5487 | 77 | 0.8866 | 0.6007 |
| 33 | 0.8658 | 0.5529 | 78 | 0.8869 | 0.6015 |
| 34 | 0.8429 | 0.5008 | 79 | 0.8872 | 0.6022 |
| 35 | 0.8454 | 0.5061 | 80 | 0.8875 | 0.6028 |
| 36 | 0.8476 | 0.5107 | 81 | 0.8877 | 0.6034 |
| 37 | 0.8499 | 0.5156 | 82 | 0.8879 | 0.6038 |
| 38 | 0.8519 | 0.5200 | 83 | 0.8882 | 0.6044 |
| 39 | 0.8539 | 0.5244 | 84 | 0.8884 | 0.6048 |
| 40 | 0.8558 | 0.5285 | 85 | 0.8886 | 0.6054 |
| 41 | 0.8575 | 0.5324 | 86 | 0.8888 | 0.6057 |
| 42 | 0.8592 | 0.5363 | 87 | 0.8890 | 0.6062 |
| 43 | 0.8608 | 0.5399 | 88 | 0.8892 | 0.6066 |
| 44 | 0.8623 | 0.5433 | 89 | 0.8893 | 0.6068 |
| 45 | 0.8638 | 0.5466 | 90 | 0.8895 | 0.6073 |

Table 1 (Contd.)

| Drift Tube Number | T x R Mode 1 (P) | T x R Mode 2 (D) | Drift Tube Number | T x R Mode 1 (P) | T x R Mode 2 (D) |
|---|---|---|---|---|---|
| 91 | 0.8896 | 0.6076 | 108 | 0.8912 | 0.6104 |
| 92 | 0.8898 | 0.6080 | 109 | 0.8912 | 0.6105 |
| 93 | 0.8899 | 0.6082 | 110 | 0.8912 | 0.6104 |
| 94 | 0.8900 | 0.6085 | 111 | 0.8912 | 0.6105 |
| 95 | 0.8902 | 0.6088 | 112 | 0.8913 | 0.6105 |
| 96 | 0.8903 | 0.6090 | 113 | 0.8913 | 0.6105 |
| 97 | 0.8903 | 0.6091 | 114 | 0.8913 | 0.6105 |
| 98 | 0.8905 | 0.6094 | 115 | 0.8913 | 0.6105 |
| 99 | 0.8906 | 0.6097 | 116 | 0.8913 | 0.6103 |
| 100 | 0.8907 | 0.6097 | 117 | 0.8914 | 0.6104 |
| 101 | 0.8908 | 0.6100 | 118 | 0.8913 | 0.6102 |
| 102 | 0.8905 | 0.6089 | 119 | 0.8914 | 0.6103 |
| 103 | 0.8909 | 0.6102 | 120 | 0.8914 | 0.6101 |
| 104 | 0.8910 | 0.6102 | 121 | 0.8914 | 0.6101 |
| 105 | 0.8910 | 0.6103 | 122 | 0.8913 | 0.6099 |
| 106 | 0.8910 | 0.6103 | 123 | 0.8914 | 0.6099 |
| 107 | 0.8911 | 0.6105 | 124 | 0.8913 | 0.6097 |

sufficient voltage is available for this mode of deuteron acceleration if the voltage level of the linac is equal or even slightly less than that needed for proton acceleration. Injection will, of course, have to be at half the normal energy, i.e., at 375 kev.

Since the variation of RT along the linac is different from the m = 1 case the optimum "flattening" of the tank would be somewhat different; however, since more than sufficient voltage is available the "flatness" may not be as critical as with protons.

Since the deuterons at any point have the same momentum as the protons at the same point, all magnetic focusing parameters will be unchanged. However, the rf defocusing at the gaps will be about twice what it is for protons*. This moves the operating point to the left in the stability

*The defocusing field at a gap is proportional to $E_o RT\ K_m I_1 (K_m r)$; $E_o RT$ is half what it is for protons, while $K_m I_1 (K_m r)$ for m = 2 is about four times what it is for m = 1.

diagram (Fig. 20 of the above-mentioned reference), but probably not too far to impair good operation.

This mode of operation may be tried by seeing whether, with the preaccelerator at half normal voltage, the $H_2^+$ ions that always are produced to a certain extent in the ion source would be accelerated.

## Discussion

N.D. West (Rutherford): I would like to point out that $H_2^+$ acceleration was tried with the Nimrod injector. It seemed to us that the threshold rf field for acceleration was not very different for that of protons. We only spent about 10 minutes doing this and have not further investigated this.

J.P. Blewett (BNL): Let me point out another difficulty with deuteron acceleration and that is that neutron levels and activation levels would be greatly increased from deuterons hitting the drift tubes.