ACCELERATION AND EJECTION OF DEUTERONS OF THE DUBNA SYNCHROPHASOTRON

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Summary

Some units of the Dubna Synchrophasotron have been readjusted for accelerating deuterons up to 10 GeV. The linac accelerating structure and rf-supply of the Synchrophasotron have been modified. Physics experiments with the deuteron beam have been started.

Introduction

The arrangement for deuteron acceleration described below accomplishes the previous suggestion [1] which had indicated a possibility of utilizing the Synchrophasotron for deuteron acceleration. The idea of the suggestion was to modify the operating systems (pre-injector, linac, synchrotron) so that the deuterons should have half the proton velocity i.e., the momentum value should remain the same.

Readjustment of the Injector

The operation of the ion source with a palladium filter on deuterium does not practically differ from its operation on hydrogen. At present the 9.4 MeV proton linac (Linac-9) with grid focusing is used as an injector in which deuterons are accelerated in traversing one unit cell in two rf cycles [2]

The equality $\beta_d = \beta_p/2$ (where the indices d and p are deuterons and protons respectively) requires that the preinjector voltage be reduced by a factor of two, to 285 kV.

From the well-known equality for the cell length, $L_n = q\beta_n\lambda$ (where q is the number of the rf periods during which a particle traverses one unit cell and λ is the wave length) it follows that the injection of deuterons into the linac at half the proton velocity makes it possible to accelerate them at q=2; the existing cell lengths and the rf frequency (143.5 MH_z) are unchanged. In this case the increase of the deuteron velocity at the gap and its final velocity are one-half that of protons.

Calculations show, however, that when the gap lengths remain unchanged at q=2 the region of stable phases is reduced to zero, since the transit time α_d is 0.5τ (τ is rf period).

It was necessary to reduce α_d to 0.25, which demanded some readjustments in the Linac-9 accelerating structure. Special rings mounted on the drift-tubes made it possible to reduce the accelerating gaps by half. But, since the transit time factor, T, drops sharply in the input part of Linac-9 (Fig. 1, curve 2), it was necessary to produce a negative field-tilt along the accelerator length (-200%) and to make the drift-tube aperture variable so that the dependence of T_d on β_d (curve 3) should approach the dependence of T_p on β_p (curve 1).

Experiments on deuteron acceleration in Linac-9 were performed after these modifications were made. Particles accelerated in the pre-injector up to an energy of 285 keV were easily trapped in the accelerating process at q=2. Suitable adjustments of the Linac 9 resulted in a deuteron pulse current of about 200μA. which was 6-7 times less than the proton one. Such a decrease may be explained by the violation of the focusing conditions in the pre-injector at low voltage. As a result, the parameters of the beam injected into the Linac-9 become worse.

Two-Gap Buncher

A method for beam bunching at the linac input with the help of a two-gap buncher at large space charge densities has been considered in ref./3/. A higher effeciency of such a buncher compared with the one-gap klystron buncher is due to essential reduction of the drift space. The distances between the mid-gaps of the buncher are determined by the dependence

$$L = k_1 \beta_0 \lambda$$

where k_1 can have the values of 1.5, 2.5, 3.5, etc; β_0 is the initial velocity of particles.

A further development of this method leads to a new design of the two-gap buncher, which is the combination of the latter with the input part of the linac accelerating structure.

The distance between the second mid-gap of the buncher and the first mid-gap of the linac is determined by the formula:

$$\ell = \left(K_2 + \frac{\pi/2 - |\varphi_s|}{2\pi} \right) \beta_0 \lambda$$

where K_2 = 0.5, 1.5, . . . ; φ_s is the synchronous phase of the linac.

A version of the combined buncher at injection into the 5th gap of the Linac-9 accelerating structure was made. The first four tubes were replaced by some others so that the 3d and 4th gaps served as a two-gap buncher and the transit time factor for the first two gaps was equal to zero. Therefore, the particles missed the first two gaps without changing their initial energy (in the first approximation). The particles were bunched in the 3d and 4th gaps and the resonance acceleration began in the 5th gap. The necessary injection energy was increased up to 525 keV. This resulted in increasing the current in the linac input by 2.5-3 times and the linac output current by 5-6 times (up to 1000μA).

Fig. 2 shows the input part of the accelerating structure of the Linac-9 for protons (continuous contour) and for deuterons (dashed contour, shaded area) for the injection into the 5th gap. The scale on the z-axis is maintained.

Fig. 3 shows the curves of the deuteron phase bunching in the two-gap buncher in the $w/w_0 - \varphi_4$ co-ordinates (where φ_4 is the particle phase in the 4th gap). The dashed lines of Fig. 3 indicate the phase trapping limits of the deuterons into the accelating process (3 φ_s).

The use of a debuncher behind the Linac-9 allowed the double increase of the beam intensity in the Synchrophasotron.

Deuteron Acceleration

Since the deuteron and proton momenta are equal at the Linac-9 output, deuteron injection was not difficult to achieve. Relative particle losses from linac to the equilibrium orbit are approximately the same. The 50% decrease in deuteron velocity at injection in comparison with the proton velocity also requires doubling the rf-range of the Synchrophasotron. Since the master generator and the output cascade of the accelerating station do not provide such a range, deuteron acceleration in the ring is accomplished in two stages: on the second harmonic of rf-voltage from 0.2 to 1.44 MH_z (the deuteron momentum is 11 GeV/c)[4].

The direct transition from one harmonic to another (with one accelerating station) is impossible because of transient processes at returning. Such a transition is ruled out with the accelerating voltage switched off and the magnetic field increasing as the time interval of the returning is much longer in comparison with the time of the beam presence at the orbit ($\approx 600\mu s$). The transition from one harmonic to another at a constant magnetic field is more convenient[5]. In this case the duration of the transient processes in the rf system become unessential.

The transition from the second to the first harmonic occurs on the flat part of the 0.13 T magnetic field, where switching off, returning, and "retrapping" are carried out. The duration of the flat part is about 60 ms. The oscillogram from pick-up electrodes (Fig. 4) shows the first stage of the deuteron acceleration and the transition to the second one. The rf-system is returned during switching off the accelerating voltage. The intensity signal drops to zero at this time (t_2 - t_3 interval) since the bunch is spread along the orbit.

The maximum beam trapping into the second stage was observed at the optimal shape of "step" in the magnetic field, with the appropriate increase, and the level of rf voltage and the radial position. With these conditions as much as 90% of the beam was retrapped. These processes turned out to be sensitive to imperfections of the magnetic field. The presence of even small ripples leads to an appreciable reduction of the retrapping efficiency. The total coefficient of the particle losses was about 40%. The deuteron intensity was found to be about 10^{10}/pulse at the end of the accelerating cycle.

Ejection

For the ejection of the deuteron beam the resonance extraction system[6] is used. The layout of the extraction apparatus and initial part of the beam channel are shown in Fig. 5. The resonance windings are located on the poles of quadrants I and II of the Synchrophasotron. The septum magnet (M-1), moving vertically, is installed in the vacuum chamber between quadrants I and III.

Emulsion chambers were irradiated by deuterons not far from the first image (F, Fig. 5 and Fig. 6) at momenta from 4.5 GeV/c to 9.4 GeV/c.

Experiments have been started with the use of nuclear electronics. The re-adjustment of the Synchrophasotron from one regime to another takes 2 or 3 days. The main part of this time is required for restoring vacuum in the Linac-9 tank.

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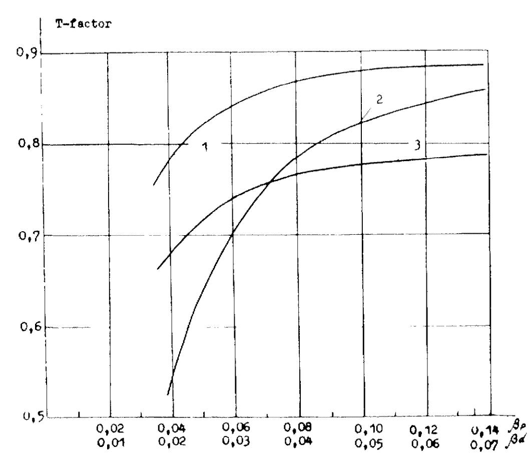

Fig. 1. Transit time factor for the Linac-9.

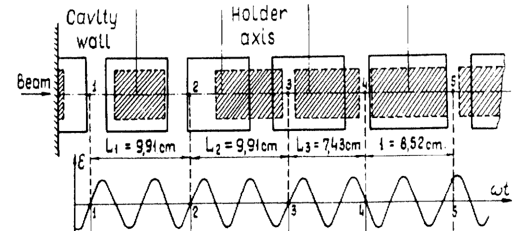

Fig. 2. Drift-tube geometry.

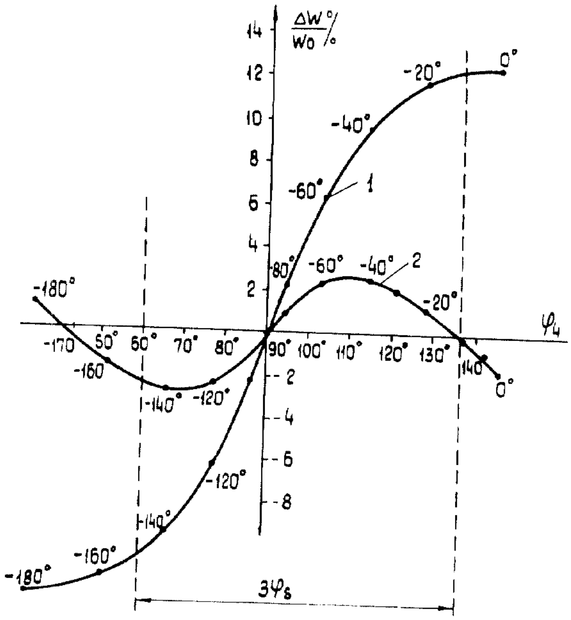

Fig. 3. Curve 1 - energy spread behind first buncher gap; Curve 2 - energy spread behind second gap.

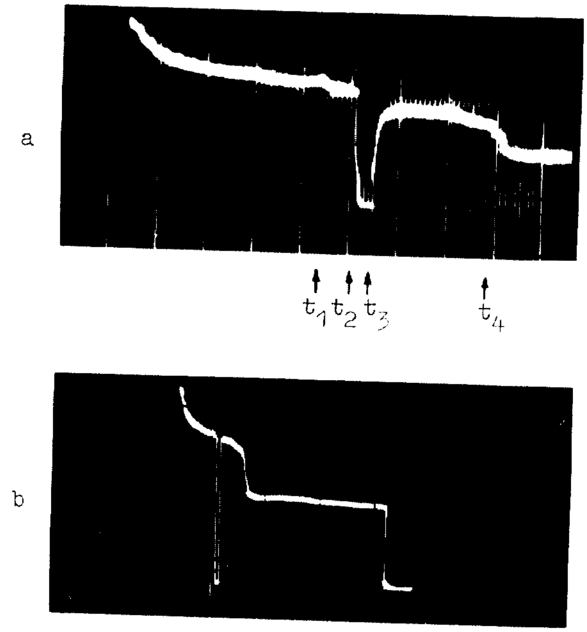

Fig. 4. Intensity oscillograms.

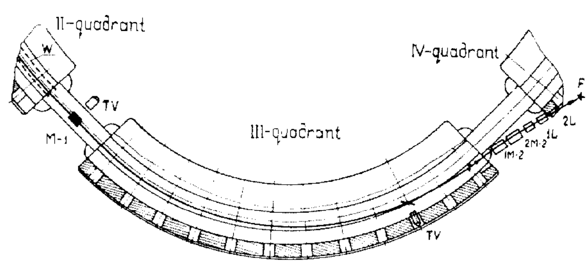

Fig. 5. Layout of the ejection apparatus and the proton channel.

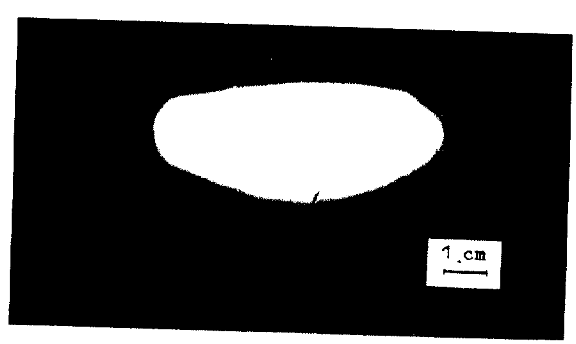

Fig. 6. Pictures of the deuteron beam close to the first image.