ACCELERATION OF He_4 IONS IN THE APF STRUCTURE AND THE LINAC I-2 FOR INJECTION INTO 10 GeV SYNCHROTRON

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The first Alvarez tank of the linear proton accelerator I-2 (used as an injector for the 10 GeV synchrotron) cannot be used for the acceleration of He_4 ions because of the $2\beta\lambda$ mode chosen at the design stage. For this reason the task of acceleration of the He_4 beam and its injection into synchrotron can be solved if instead of the first tank a supplementary APF structure is used in conjunction with the second tank of the linac, which will be operated in the $2\beta\lambda$ mode (instead of $\beta\lambda$ mode for protons). The supplementary APF structure providing the accelerating field gradient of 7.5 MV/m is installed in the matching channel and accelerates He_4 ions to an energy sufficent for their injection into the second tank. Though the linac's acceptance becomes lower, this scheme was considered feasible.

The acceleration of the He_4 ions in the existing linac I-2, and subsequently in the synchrotron, required a series of investigations.

He_4 ions were produced in the existing duoplasmatron ion source, developed about 20 years ago and used up to the present for the production of protons.[1] The mechanical design of the source permits changing the working gas rather quickly without any difficulties. Taking into consideration that the share of He_4^{2+} ions produced by the source was too small to provide routine operation of the linac, and that at the same time the current of the He_4^+ beam reached a level of several hundred mA, it was decided to use He_4^+ ions. After the optimization of the parameters, the pulse current of the He_4^+ beam at the output of the source reached 300 mA, and the pulse duration was 15 μs.

The proton linac I-2 consists of a 700 kV preinjector, the matching channel, and two Alvarez tanks (6 m and 12 m long); all are mounted in one vacuum chamber.[2] A two $\beta\lambda$ mode for the first tank was chosen at the design stage in the early sixties in order to facilitate the installation of quadrupole lenses inside the drift tubes. The second tank was designed to operate in a $\beta\lambda$ mode (for protons).

In order to accelerate He_4 ions, the first tank should be operated in at least a 4 $\beta\lambda$ mode at least. But in this case the maximum permissible level of the RF accelerating field is much lower than the threshold level for acceleration of He_4^+ ions in $4\beta\lambda$ mode, and as it concerns He_4^{2+} ions this limitation leads to the rapid decrease of the capture up to zero even in the beginning of the first tank.

The same consideration is valid for the acceleration of He_4 ions in the first tank operating in $2\beta\lambda$ mode, even in the case of additional acceleration between the preinjector and the first tank.

The second tank of the linac can be used for the acceleration of He_4^{2+} ions up to 6 MeV/u in $2\beta\lambda$ mode. At the output energy indicated, there is no need to change the input parameters of the synchrotron after the conversion from protons to He_4 ions. Also, the RF field levels in the second tank needed for the acceleration of He_4^{2+} ions are almost the same as for protons. This facilitates the conversion from one type of ions to another.

In order to accelerate He_4^{2+} ions in the second tank, it is necessary to provide 1.5 MeV/u at its input. The existing preinjector cannot provide such an energy, so an additional acceleration section is needed. As the first tank is inseparably linked with the second, it was decided to install the additional section in the matching channel place of the viewing chamber and one of the steering magnets. The total length of the removed elements is about 1 m.

For additional acceleration the APF structure was developed, which can provide a rather high accelerating field gradient of 5-10 MV/m. The structural scheme of the facility comprising the APF structure and the second Alvarez tank is given in Fig. 1.

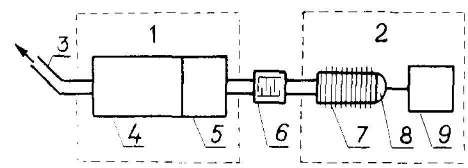

Fig. 1 The structural scheme of He_4^{2+} ion beam acceleration in the APF structure and linac I-2

1. Linac I-2	6. APF structure
2. Preinjector	7. Accelerating tube (column)
3. To PS	8. Ion source
4. The second tank	9. Pulse transformer
5. The first tank	

The vacuum chamber containing the APF structure and the stripper is about 1 m long and is located between the preinjector and the first tank. The parameters of the APF structure (see Fig. 2) are given in Table 1.

Table 1

Specific charge, Z/A	1/4
Input energy, MeV/u	0.17
Output energy, MeV/u	1.5
Working wave length, m	2.02
Maximum RF power consumed (pulse), MV	1
Minimum diameter of channel aperture, mm	8
Maximum field strength on the axis, MV/m	17
Tank length, m	0.75
Number of accelerating gaps	19
Diameter of the electrodes, mm	50

The input aperture of the APF structure is 10 mm.

The structure was in operation on a round-the-clock basis for a few weeks at the rated RF field level.

At the output of the linac the current of the He_4^+ beam was 2.5 mA, but it should be mentioned that it was detected at the distance of 20 m from the APF structure. Also the instantaneous energy spectra of the He_4^+ beam at 1.5 MeV/u

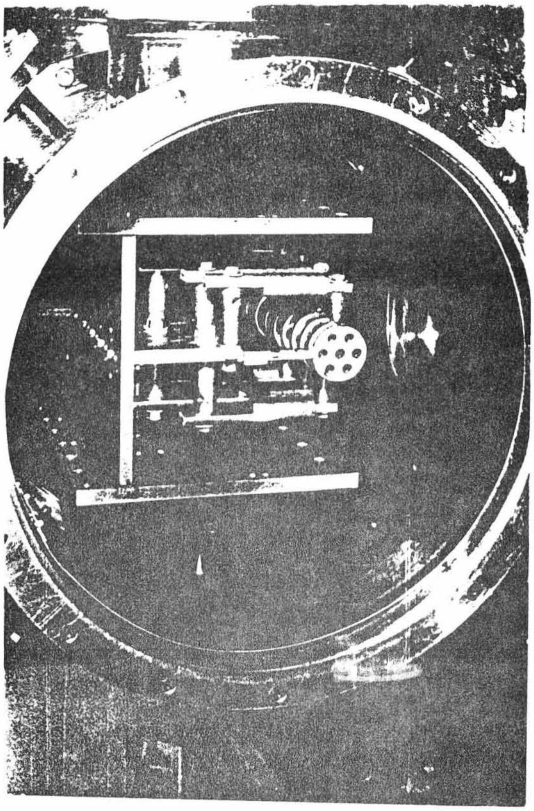

Fig. 2 APF structure

were measured. The results of the measurements are given in Table 2.

Table 2		
Time, μs	Spectrum width, %	Spread, %
4	$\pm$ 1.01	- 0.22
4	$\pm$ 1.03	- 0.17
6	$\pm$ 1.04	- 0.06
7	$\pm$ 1.05	- 0.05
8	$\pm$ 1.06	- 0.01
9	$\pm$ 1.09	+ 0.07

The stripper located at the output of the APF structure is designed to produce He_4^{2+} ions. It is made of thin carbon foil with equilibrium thickness of 37 $\mu g/cm^2$. The diameter is 8 mm, stripping factor - 0,95.

After the stripper, the He_4^{2+} beam drifts through the first tank. Unfortunately the design parameters of the existing drift tube quadrupoles do not allow optimization of focusing on the helium beam.

Due to the energy spread of the ions (see Table 2), the beam bunched in the APF structure becomes quasi-continuous at the input of the second tank (as the distance between the APF structure and the second tank is 7 m). That is why the bunching occurs in the second tank in the course of acceleration, leading to additional beam losses.

The increase of He_4^{2+} ion beam current at the output of the second tank by changing (increasing) the synchronous phase ϕ_s (see Fig. 3) leads to additional energy spread of the ion beam (see Fig. 4). At $\phi_s = 64°$ (instead of 37° for protons), He_4^{2+} beam current was 1mA at the energy spread of $\pm$ 2%. At such a large energy spread the injection into the synchrotron is not

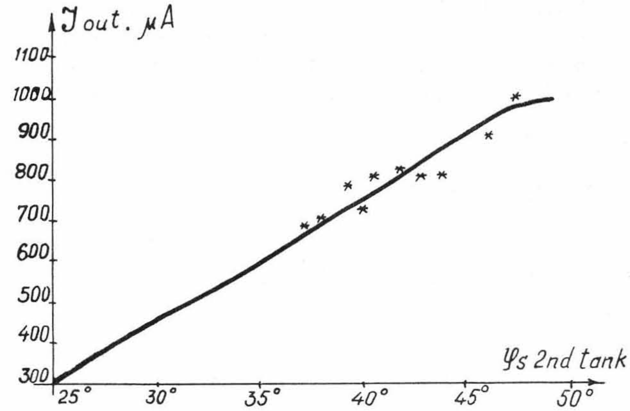

Fig. 3 He_4^{2+} beam current versus equilibrium phase in the second tank

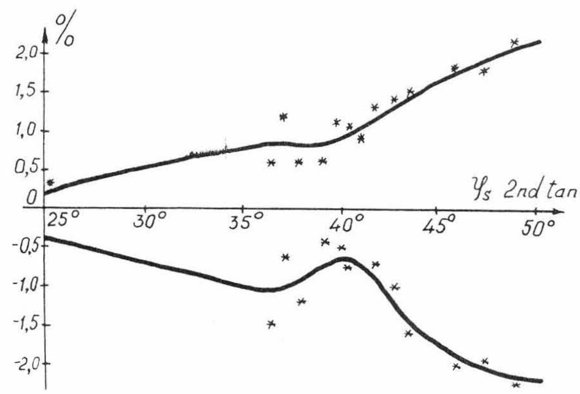

Fig. 4 Spectrum width of He_4^{2+} ion beam versus synchronous phase in the second tank

optimum. The optimum injection took place at RF field level in the second tank corresponding to 0.8 of the rated value. In this case the output He_4^{2+} beam current was 700 μA, which provided a circulation current of 500 μA in the synchrotron (or 1.10^{10} ions/pulse). The intensity of He_4^{2+} ions obtained in the synchrotron provides the opportunity to carry out experiments.

Conclusions

1. The results obtained prove the validity of theoretical calculations of beam dynamics in APF structures at the current level of a few mA. He_4^+ beam current measured at the distance of 20m from the APF structure was 2.5 mA, corresponding to 1/4 of the maximum calculated value for the given structure.

2. The width of the instantaneous spectrum is practically constant on the plateau of the pulse (in the interval from the fourth to the ninth μs) and is about $\pm$(1.01-1.09)%.

3. The results of the measurements show that the operation modes of the APF structure and the second tank provided the optimum injection of He_4^{2+} beam into the synchrotron.

4. The use of APF structures in the initial part of the linac at several MeV/u will permit a substantial decrease (by the order of magnitude) in the length of the linac.[3,4]

5. Along with such advantages as high acceleration rate and relative simplicity, the constructed APF structure possesses substantial limitations: the output current is rather low due to the small aperture; the capture is also low (40-

50° versus 110-180° for Alvarez-type tanks); and the high level of the strength of the electric field in the structure (up to 220 kV/cm versus 20-30 kV/cm for Alvarez type tanks) makes reliable operation rather complicated.

6. In order to increase the output current in the APF structure, it is reasonable to optimize the injection parameters of the beam (for instance by prebunching of the beam) or to use a multi-beam scheme.

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