DEVELOPMENT OF THE NEW PRE-STRIPPING SECTION FOR LUMZI

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The investigations have been performed on the development of a multipurpose complex based on the linear heavy ion accelerator for high-intense light ion beam production. The investigations were carried out with theoretical and experimental methods. As a result physical prerequisites were developed for creation of the pre-stripping section (POS-4) which enables acceleration of high-current light ion beams with the average current of 1-0.5 mA.
PACS numbers: 29.17.+w

The main task for the linear multicharged ion accelerator (LUMZI, at the NSC KIPT) was fundamental investigations in the field of nuclear physics and radiation material technology. After being constructed it underwent a number of improvements, and in 1989 its upgrade was completed on the basis of an efficient accelerating structure of the interdigital type excited on the H_{111} wave [1]. Some other systems were updated according to the latest achievements in RF power production, multicharge ion sources, high-voltage equipment, and beam control and diagnostic systems.

The LUMZI consists of two sections - a pre-stripping section (POS) and post-stripping one (OS) rated for the energy of 0.975 and 8.5 MeV/nucleon, respectively. The average beam intensity at the output of the sections is (10^{12} - 10^{10}) and (10^{11} - 10^{9}) particles/s for ^{14}N, ^{20}Ne, ^{40}Ar, and others. The POS section is designated for acceleration of ions of arbitrary kinds with a mass-to-charge ratio of $A/q \leq 15$, and the OS - for $A/q \leq 5$.

The latest events have demanded a conversion of the accelerator to solving new fundamental and applied problems. Among them the most promising are: track membrane production, radionuclide production, light ion beams (protons, α-particles) accelerated to energies of 8.5 MeV/nucleon and with average current of 1 - 0.5 mA. It will enable to produce rather intense neutron beams (10^{12} - 10^{14}) nucleon/s, and thus to give a possibility to carry out investigations in neutron physics, nuclear engineering and transmutation of nuclear waste, medicine (boron neutron capture therapy). The LUMZI features allow to solve these problems effectively. However, the requirements on heavy ion beams are different for different tasks. For track membrane production ions with a mass as high as possible are required, and for radionuclide production requires light ions (protons, deuterons, helium ions (^3He, ^4He) with an average current as high as possible (from 100 to 1000 μA). It is practically impossible to combine these requirements for a single accelerator. Here the pre-stripping section is a bottleneck.

The pre-stripping section rated for acceleration of ions with a mass-to-charge ratio of $A/q = 4$ (POS-4) should be mounted alongside the existing POS-15 section with parallel beam transfer to the input of the main LUMZI section. The reduction in A/q from 15 to 4 will allow to reduce the pulsed RF power supply of the accelerator and to increase the average beam current. That will enable acceleration of light ions (p, d, ^3He, ^4He). Therefore, a small cavity will be necessary for acceleration of these particles from energy of 30keV/nucleon to energy of 1MeV/nucleon. This beam (after ^3He and ^4He stripping) will be injected in the existing post-stripping section by parallel transfer and will be accelerated to 8.5 MeV/nucleon. Therefore there is no principal limitations on the acceleration of protons to the full energy of 8.5 MeV, deuterons - to 17 MeV, ^3He – to 26MeV, and ^4He - to 34MeV. At the same time reduction of the A/q parameter from 5 to 1 (for protons) and to 2 (for deuterium and helium) will allow the post-stripping section operation in the facilitated mode. The level of RF power for the proton acceleration will be 25 times lower than the present one, and for deuterium and helium - 6.25 times lower. This will enable to increase considerably the time duty factor (the pulse repetition and pulse duration) that would enable obtaining the indicated average beam current.

The interdigital accelerating structure forms a basis of the pre-stripping section. Operating experience on this structure has been accumulated with construction of the pre-stripping and main sections of LUMZI [2, 3]. The accelerating structure of interdigital type with a uniform distribution of the accelerating field in gaps between the drift tubes provides the rate of acceleration of 3-3.5MeV/m. Thus at the length of 1.3 m it is possible to accelerate ions with $A/q = 4$ with average accelerating field gradients in the accelerating gaps of 80 kV/cm.

The accelerating structure of interdigital type excited at the H wave differs from the unloaded cylindrical cavity excited on the wave with a transverse electric field component in a considerable drop in the eigenfrequency. Dependently on the load nature the eigenfrequency of the loaded cavity decreases in 3 - 4 times. Such a very useful phenomenon allows to reduce at the same extent the transverse sizes or to increase the operational wavelength for acceleration of the heavy ions.

The main requirement for linear acceleration is the fulfillment of the condition of synchronism of the aaccelerated ion movement in the RF field by increasing the lengths of the accelerating gaps proportionally to increase in velocity of particles travelling through the cells. However, the irregularity of the sizes of the accelerating structure elements causes deterioration of the

ВОПРОСЫ АТОМНОЙ НАУКИ И ТЕХНИКИ. 2001. №3.
Серия: Ядерно-физические исследования (38), с. 128-130.

uniformity in accelerating field distribution and changes of operational wave frequency. Therefore the change of longitudinal cell dimensions implies the necessity of the appropriate adjustment at the cost of the change of transverse dimensions of the accelerating structure elements (the cavity, drift tubes) or at the cost of auxiliary adjusting devices.

The choice of the operational wavelength was made from the assumption that for excluding the loss of particle in the main section with their capture into acceleration, the length of the main section should be equal or multiple of the wavelength. From the considerations on the simplicity of the compact accelerator structure and unification of the RF equipment we decided that the operational frequency of the pre-stripping section should be equal to the operational frequency of the main section, 47.2 MHz.

The calculations of the accelerating section and beam dynamics were carried out for the new version of the simultaneous radial and phase stability of the bunches of accelerated particles, namely alternating phase focusing with a moving bunch center [4, 5]. Its main parameters are presented in the Table I.

Table I

Parameters of the POS-4 accelerator

Ion energy at the input, keV	30
Ion energy at the output, keV	975
Mass-to-charge ratio, A/q	4
Operational frequency, MHz	47.2
Electric field gradient in gaps, MV/m	8.0
Length of the accelerating structure, m	1.3
Diameter of the accelerating structure, m	0.7
Drift tube number	16
Drift tube aperture, mm	16-20
Synchronous phase of the bunching section, grad	-40
Synchronous phase of the focusing section, grad	+45
Number of bunching sections	4
Number of focusing sections	3
Acceleration rate, MeV/m	3.0
Longitudinal capture, grad	120
Radial acceptance, mm·mrad	3100
Normalized radial acceptance, π·mm·mrad	2.4
Time duty factor, %	2.5

As one can see from the Table I that the accelerating structure based on the alternating phase focusing with the moving bunch center has small longitudinal and transverse sizes, is simple in construction, and possesses a high longitudinal capture. The radial acceptance is at the level typical for the quadruple focusing with essential simplicity of drift tubes. The application in the POS-4 of interdigital accelerating structure reduces considerably the RF power consumption.

Using the results of the calculations of the longitudinal sizes a model was manufactured for determination of electrodynamic characteristics of the cavity, adjustment to the frequency, and formation of the uniform electric field distribution along the structure (Fig. 1).

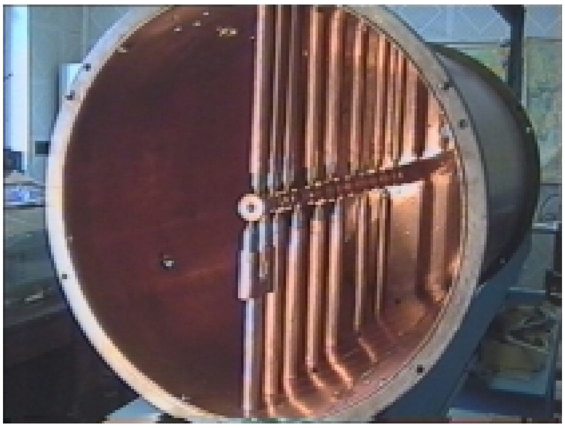

Fig. 1. The model of the LUMZI pre-stripping section (photograph).

The scale of the model was 1:2 as the most optimal from the viewpoint of reliability of the results and constructional potentials. The largest difficulty was that beforehand it is practically impossible to determine to sufficient accuracy the cavity diameter. In this connection the goal was achieved by the "successive approximations". We had to manufacture 3 cavities before the specified resonance frequency of 94.4 MHz was achieved with the uniform field distribution.

The construction of the accelerating structure is similar to that applied at the pre-stripping and main sections of the linear multicharge ion accelerator LUMZI. The drift tubes are connected in turns with conducting stems to diametrically opposite sides of the cavity forming the interdigital system (Fig. 2).

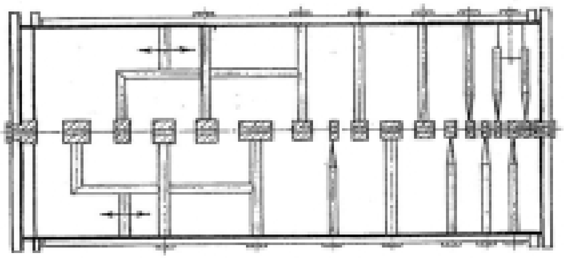

Fig. 2. The construction of the POS LUMZI section.

The arrangement and the number of the adjusting resonance elements were determined. At the output end of the structure two end resonance elements are formed from one even (16) and one odd (15) drift tubes: these drift tubes are mounted on the longitudinal carrying element which in its turn is fastened at the side cavity surface forming the end quarterwave resonance adjusting element (Fig. 2). With shifting the pistons placed between cavity walls and longitudinal carrying elements we changed the electric field distribution. The electric field strength on the cavity axis was determined on the perturbation contributions by a metallic body to the gaps of the accelerating structure.

The previous measurements have shown that the field is concentrated in the initial part of the cavity. Varying the outer diameter of the drift tubes the electric field extent is spread over the total cavity length, and with following changes of the slit depth of the end elements the specified uniform distribution of the electric field strength along the accelerating structure field with the operational wavelength of f_l = 94.4 MHz for the H_{111} wave has been obtained. Some variations in the field distribution is due to the fact that the model is not suited to rather precise adjustment of the drift tubes. In the actual structure where the lengths of the gaps will correspond exactly to requirements of accuracy these deviations will disappear. The resonance frequency of oscillations of the H_{112} type is f_2 = 104.7 MHz, and for H_{113} mode - f_3 = 126.8 MHz, that is the structure possesses rather good dispersion.

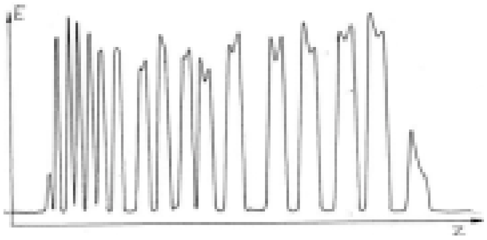

Fig. 3. The final field distribution in the gaps of the POS LUMZI model.

To accelerate heavy ions with A/q = 4 from 30 keV to 0.975 MeV it is necessary to have 16 drift tubes and two half-tubes with the outer diameter from 32 to 70 mm. The lengths of accelerating gaps and drift tubes vary from 13 mm to 87 mm, drift tube aperture varies by steps from 16 mm for the first tubes and to 20 mm for the following ones. The cavity diameter is 750 mm and the length is 1298 mm.

The Q-factor and shunt impedance measured after adjustment with the formed uniform distribution of the accelerating field, correspond to those of the full-scale POS-4 - 15000 and 150 MOhm/m. Thus, to excite the electric field of 80 kV/cm in the gaps between drift tubes, the RF generator power of 150 kW is necessary.

CONCLUSIONS

From the results of experimental investigations on the models, the geometric sizes of the elements of the interdigital accelerating structure designed for the LUMZI pre-stripping section for acceleration of the high-intense light ion beams were obtained. The constructing of the adjusting elements of the accelerating structure and its adjusting to the operational frequency were performed, the uniform distribution of the accelerating field was formed, RF parameters, Q-factor and shunt impedance were optimized. The required RF power is evaluated.

The work done shows that the reduction in the ion mass-to-charge ratio allows to increase the time duty factor by an order of magnitude and thus to bring the average current of helium and proton beam to 1 and 0.5 mA, respectively. This value exceeds considerably the output beam current of the cyclotrons used for radionuclide production all over the world.

The development of a new version of the pre-stripping LUMZI section for a light ion intense beam, POS-4, enables the creation of the general-purpose complex for efficient production of diversified, radionuclides which are necessary for medicine and high-tech industry, and to carry out investigations in neutron physics, electronuclear engineering, nuclear waste transmutation, medicine (boron neutron capture therapy).

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