DEVELOPMENT OF INVESTIGATIONS ON THE MILAC HEAVY ION LINEAR ACCELERATOR

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Abstract

On the Kharkov heavy ion linear accelerator MILAC works are carried out with heavy ion beams accelerated to 8.5 MeV/u, and development of new methods for acceleration and investigations on modernization of accelerating structures [1].

MILAC LINEAR ACCELERATOR

The Kharkov ***multicharge ion linear accelerator*** (MILAC) is a unique physical and technology complex that consists the first prestripping section PSS-15 (Fig. 1, p. 2), second prestripping section PSS-4 (Fig. 1, p. 5), main section MS-5 (Fig. 1, p. 3) and the system of the ion irradiation (Fig. 1, p. 8). The structural scheme of the accelerator is given in the Fig.1.

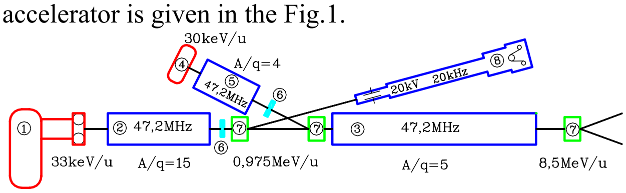

Figure 1: The structural scheme of the MILAC.

At the main and two pre-stripping sections of the MILAC linear accelerator the accelerating DTL structure on the H-wave of interdigital type (IH-structure). was applied [2].

The characteristic feature of the main section MS-5 (Fig. 1, p. 3) is its electrodynamic characteristics. An effective method was developed for adjusting the cells of the accelerating structure using additional current-carrying rods located at an angle to the supporting rod (Fig.2).

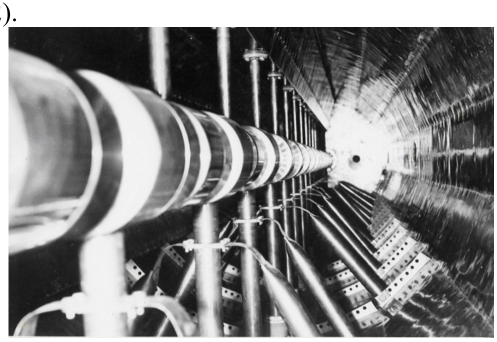

Figure 2: Accelerating structure MS-5.

This method of adjusting the inductive accelerating cell parameters allowed formation of a uniform accelerating field distribution along the structure. From one hand, this allowed to increase significantly the acceleration rate, and from the other, to form the paths of the uniform filed distribution of the controllable extension which gives a possibility to obtain the beams of intermediate energies [3]. Additionally, a method was developed for adjusting the field distribution using the ending resonance adjusting device, which represent quarter wave oscillators; on the side of the oscillator facing the side wall of the cavity a control piston is placed which can move in longitudinal direction. Such systems are installed on the input and output ends of the cavity.

The main section MS-5 11 m in length with 42 drift tubes, of which 21 contain magnetic quadrupoles gives a possibility to accelerate ions with A/q≤5 from 0.975 to 8.5 MeV/u. Total acceleration rate in the prestripping section is 3.2 MeV/m.

Second pre-stripping section PSS-4 (Fig. 1, p. 5) for accelerating only light ions with A/q≤4 from 30 keV/u to 1 MeV/u is developed. In this new section irregular interdigital (IH) accelerating structure with beam focusing by radiofrequency field (alternating phase focusing with stepped changing the synchronous phase along the focusing period) are used. After stripping this beam will be output on the acceleration line of the main MILAC section (Fig. 1, p. 3) and accelerated up to 8.5 MeV/u.

The problem of adjustment accelerating structure PSS-4 was especially difficult in connection with the non-uniform of lengths of cells mention above in structure of the focusing periods and increasing character of distribution of an accelerating field along the accelerator. Therefore it was required to apply a combination of various tuning methods The new effective inductance-capacitor tuning devices (contrivance) as rods located on the drift tube side, opposite to their holders are developed [4]. At the certain design the exact local tuning of cells is possible for carrying out not only selection of contrivance length, but also by change of a corner of their disposition concerning an axis of drift tube holders (Fig.3.).

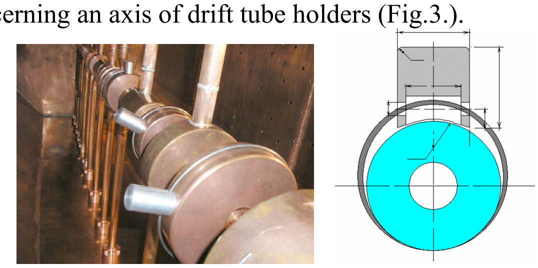

Figure 3: Accelerating structure PSS-4 with contrivance.

The high efficiency such inductance-capacitor tuning system allows to receive required electro-dynamic characteristics of accelerating structure at an identical small diameter of drift tubes, that considerably simplifies

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their design, reduces a radiating background around of the accelerator and prevents occurrence of the multypaction high-frequency discharges.

INVESTIGATIONS ON MILAC

Introduction on MILAC linear accelerator IH accelerating structures of various modifications considerably expand a scientific and applied range of researches. Experimental investigations with heavy ions beams for obtaining track-etched membranes, production of unique radionuclides, developments of proton and ion therapy, studying of radiating characteristics of constructional materials of nuclear power, research processes of fusion-fission superheavy nucleus and other problems of nuclear physics are carried out.

Track-Etched Membranes

Presently, on MILAC experimental investigations on irradiation the polymer films with heavy ion beams with the aim of obtaining track-etched membranes [5]. In the MILAC prestripping section triple-charge Ar_{40}^{3+} ions were accelerated to the energy of 1 MeV/u with the intensity of 10^{10} particles/s; PETF films 6 – 10 μm thick were irradiated, and after subsequent physical and chemical treatment it was possible to obtain experimental samples of track-etched membranes with through pores from 2 to 0.05 μm in diameter (Fig.4).

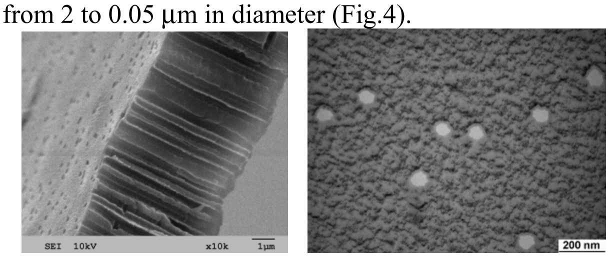

Figure 4: Pores at the cross section and the surface track-etched membrane.

To provide uniform track distribution in the polymer film with the specified density and orientation a system for ion irradiation of polymer film with horizontal beam scanning with the frequency of 20 kHz and sinusoidal voltage up to 20 kV was developed.

Radiation Investigations on Structural Materials

In connection with the forthcoming termination of the design service life of some energetic blocks at nuclear power plants in Ukraine it is necessary to develop a scientific and engineering substantiation for extending the operating lives of NPP units. The use of accelerated charged particles allows one to imitate quite completely the processes involved by radiation effects in the reactor cores under steady-state and transient operating conditions.

In experiments the ions of helium, neon and argon are accelerated at the accelerator MILAC in the two prestripping sections PSS-15 and PSS-4 to energy of 1 MeV/nucleon and in the main section MS-5 to energy of 8.5 MeV/nucleon. Thus, it is possible to imitate the process of irradiation with heavy ions of fuel element materials and other structural materials used in energetic blocks.

For investigations on the mechanical characteristics of structural materials a complex of experimental devices was developed. It is designed to study the creep, stress relaxation and active straining of samples after irradiation with accelerated ions.

A device permitting to study the creep, stress relaxation, active straining and dimension stability directly in the process of irradiation with accelerated ions was designed. In Fig.5 given are the schematic presentation and the photograph of the experimental device for investigations of plastic properties of structural materials exposed to the ion beam.

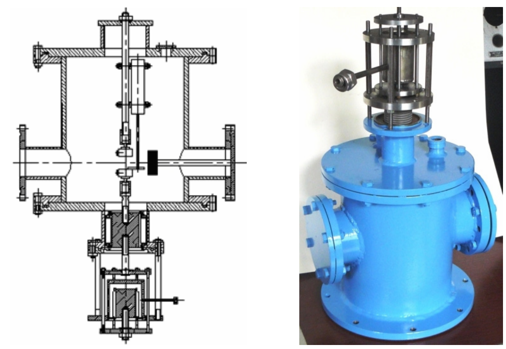

Figure 5: Chamber for investigations of plastic properties of structural materials exposed to the ion beam.

Using the developed methods and experimental devices at the accelerator MILAC it will be possible to investigate the structural materials directly in the process of irradiation with heavy ions, as well as, after irradiation.

Development of Investigations on the Nuclear Fusion of Heavy Particles

At present, 1.5 tens of supeheavy elements are obtained, but there are no direct reactions to produce, for example, a stable isotope of the element-114 with an atomic number 298 for lack of neutrons.

To produce new superheavy elements and to study their properties in the field of the assumed stability island it is necessary to develop new experimental techniques. For arrangement of experiments on studying the reactions of deep inelastic transfers during interactions of heavy ions, with a maximum yield of interesting isotopes, the choice of an initial target-beam isotope combination and kinetic beam energy is a determining factor. The most realistic description of the process of nuclear fusion is proposed in the concept of a double nuclear system. Basing on this system a series of models are constructed being successfully applied in the description of the processes of fusion-quasi-fission of heavy nuclei.

We have calculated the number of protons and neutrons in the fragments of the double nuclear system and considered possible variants of transitions which are controlled by the potential energy and are determined by its minimum value. The dynamics of transitions in the reaction of isotopes *Fe*, *Ni* and *Co with* ^{238}U for ±n, ±p, ±(n+p) allowed transitions is calculated. With a correct choice of the target-beam isotope configuration, taking into account the nucleon emission and excitation energy changing, there is a probability to direct the reaction into the channel of nucleon transfer for production of superheavy nuclei.

Using the accelerator MILAC it is planned to accelerate the ions of iron, cobalt, nickel, copper and zinc to the energy of 8.5 MeV/nucleon. In experiments the target of uranium, bismuth, lead and other heavy metals will be used. When carrying out experiments on the study of the reactions of deep inelastic transfers there is a need for heavy ion accelerators with controlled beam energy. The team of specialists working at the accelerator MILAC facility has a wide theoretical and experimental experience in smooth variation of ion energy, including the beam ion energy of the main section MS-5 [3].

Radionuclides for PET Diagnostic

For investigation with PET it is important to choose a radionuclide having a low maximum energy of β^+-particles which provides high resolution of the image. ^{18}F having the maximum energy of β^+-particles of 635 keV is the best among the other radionuclides. Ideally, average period of life of radionuclides should be of the same order as the time necessary for investigating

^{18}F is relatively long living among short living isotopes ($T_{1/2}$=109.7 minutes) which radiopharmaceutical preparation takes the main part in the development of positron-emission tomography. PET investigations requires from 1 to 4 hours for scanning from the moment of the admission of the preparation.

Production of considerable amount of fluorine-18 (about 1 curie per an hour) at linear accelerator MILAC is possible with $^{18}O(p,n)^{18}F$ and $^{16}O(\alpha,pn)^{18}F$ reactions with energies 8.5 and 34 MeV for protons and helium ions, respectively. In the Fig. 6. the function for excitation of $^{16}O(\alpha,pn)^{18}F$ reaction is shown. It is easily seen that at the energy of 34 MeV it has the maximum.

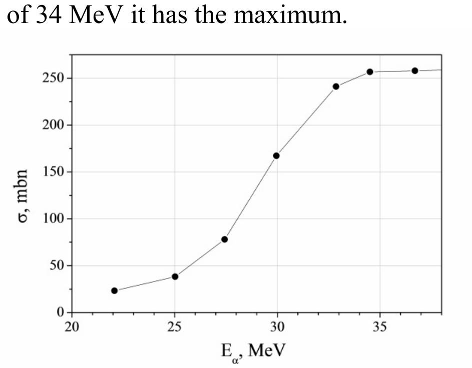

Figure 6: The function for excitation of $^{16}O(\alpha, pn)^{18}F$.

After start prestripping section PSS-4 on linear accelerator MILAC acceleration of ions of helium up to energy 34 MeV at an average intensity of helium ion beam up to 10 µA is planned.

A system for target irradiation was created; in the targets nuclear reactions run. Production process of ^{18}F radioactive fluorine from CeO_2 oxide respectively to the nuclear reaction $^{16}O(\alpha, pn)^{18}F$ was studied.

Ion Therapy

In Ukraine medical centers of proton and ion therapy are not at all. The oncological disease and mortality rate in our country is highest throughout Europe and the survival rate is lower by a factor of 2.5 then in other countries. Widespread investigations demonstrated that the best method of overcoming the tumor resistivity is the use of a close-ionizing radiation with linear energy losses of 50÷100 KeV/µm. Practical results revealed a high efficiency of radiation treatment with carbon ions. In many cases the effective treatment is ensured by the combined use of proton and ion beams. Therefore, the most complete center of radiotherapy should provide the radiation treatment by carbon ions and protons.

After starting the new prestripping section PSS-4 at the linear accelerator MILAC it will be possible to accelerate protons to energy of 8.5 MeV, helium ions to energy of 34 MeV and carbon ions to energy of 102 MeV. For further acceleration of above mentioned ions it is necessary to construct a synchrotron having 20 m in diameter. Then ions could be accelerated to the controlled energy from 50 to 400 MeV/nucleon being necessary for the ray therapeutics. Establishing of the center of radiotherapy has a reason, as it is located near the accelerator MILAC of the research institute of medical radiotherapy possessing a necessary therapeutic base and highly qualified personnel having a great experience in treatment of oncological patients by surgical, chemotherapeutical and radiation methods.

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