PROJECT OF THE INDUSTRIAL HEAVY ION LINAC FOR PARTICLE TRACK MEMBRANES (PTM) PRODUCTION

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ABSTRACT

A technological complex for industrial politrack membrane production based on a RF pulse heavy ion linac is under way now at the Electronic Device Enterprise "Tenzor" in Dubna. In accordance with the technology requirements to produce 20 μm thick PTMs 1.7 MeV/amu very heavy ions, tungsten for example, with intensities of the order of $10^{11} - 10^{12}$ p/s and pulse repetition rate of 25 pps should be reached. The design linac of 30 m total length consists of 35 kV injector based on the MEVVA type ion source, two APF resonant accelerator sections, both 6 m long, with a stripper in between, and an output channel of 8 m long with a beam sweeper to form a wide homogenious beam at the moving polymer film-target. To ensure effective beam formation the 3m long 40.7 MHz RFQ stage arranged between injector and prestripper section is considered.

INTRODUCTION

Membrane technologies caught on and were widely accepted in the world because they are cost-effective and adventageous ecologically due to possibilities to utilize many kinds of contaminants in safe productions which use membrane technologies.

Recently a new type of microfiltration by means of PTM with regular and strictly controlled porous structure and shape has found extensive applications in industry and medicine. This type of the microfiltration includes membranes obtained by nuclear physical methods [1]. The process of microfilter production is based on irradiation of thin polymer film with extremely heavy fast ions followed by etching of their primary latent tracks in the film until through pores are formed. To promote better etching, the irradiated polymer film is usually exposed to ultaviolet light or chemical sensitization [2]. This PTM technology has essential attractions in comparison with other membrane technologies, in particular

- high homogeneity and uniformity of formed pores,
- high selectivity with respect to required component,
- wide range of possible pore sizes (from 0.015 to several μm),
- very low adsorption of components by the membrane surface,
- high thermal and chemical stability, etc.

Operating parameters of PTMs depend on membrane thickness, pore diameter, pore density, spread in pore diameters, pore shape and acceptable mechanical strength. Selectivity of the track etching is growing up quickly with atomic number of fast ions. Secondly, to produce membranes of a rather high porosity of 20% or even more their thickness must be not less than 20 μm because of strength requirements. Production of membranes of more than 30 μm thick is probably non-expedient because of increasing sophistication of the linac facility and appearance of residual radioactivity which is unacceptable for an industrial complex.

ACCELERATOR CONCEPTUAL DESIGN

The approach to create a specialized heavy ion linac for industrial irradiation complex for PTM production has a number of challengies in comparison with an ordinary heavy ion linac. First, it must allow to reach high production rate and capacity ($\geq$ 0.5 Mln.m^2/year) combined with high quality of irradiation (porosity $\geq$ 20%, irradiation nonuniformity $\leq \pm 5\%$, wide range of film thickness, i.e 10-30 μm). Secondly, the installation must be energetically effective. At last, the industrial linac must be extremely compact, reliable and convinient for maintainances by non-specialized enterprise personnel. We suppose that alternating phase focusing (APF) linac is the most advantageous system for the industrial PTM facility.

The layout of the 1.7 MeV/amu heavy ion linac for industrial PTM production is shown in Fig.1. Pulse beams of tungsten ions with the designed charge +4, being produced in the MEVVA type ion source, pass than through a high voltage injector terminal of 35 kV and the static matching channel. The RF matching of the beam, its bunching and preliminary acceleration is carried out in the 3m long RFQ. The main acceleration is executed in two alternating phase focusing (APF) sections. The intermediate beam recharge up to equilibrium charge of +16 is provided by a gas stripper at the energy of 0.42 keV/amu. As the RFQ section so the APF prestripper section are supplied with pulse RF power at the industrially permitted frequency of 40.7 MHz (under maximum pulse length of 800 μs and repetition rate of 25pps), while the stripped beam is accelerated at a doubled frequency of 81.4 MHz. The equipment for the beam formation at the irradiation target with a drift space of 8 m total is provided for acceptable pulse irradiation of a wide (up to 400 mm) constantly moving roll of the polymer film. Maximum permissible number of parasitic pores

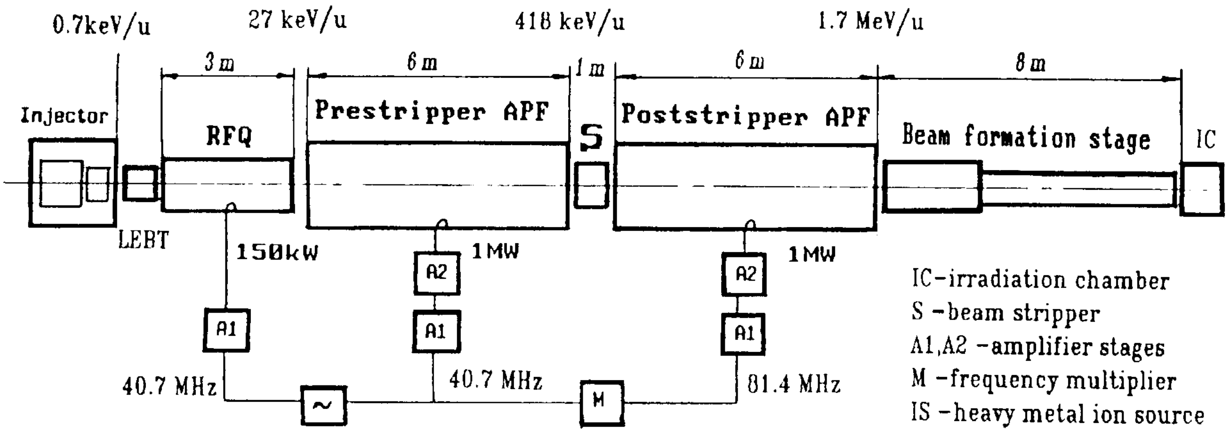

Fig. 1: Schematic layout of the industrial linac for politrack membrane production

comply with the case when the film porosity per one pulse does not exceed 0.8%. So the getting of optimum porosity of 20% corresponds to a pulse irradiation under variable angles of the incident ions with the repetition rate of 25 pps in accordance with restrictions on percentage of parasitic (doubled and more) pores.

Injector

The injector for the industrial complex must maintain stable and reliable pulse supply for the linac structure with heavy ions. A rather low injection potential of ≤ 35 kV was chosen for the sake of exploitation requirements.

The heart of the injector is a vacuum ark source of heavy metal ions developed in ITEP[3]. We suppose this kind of source, usually called MEVVA, is now the most suitable source for high current heavy metal beam production. The source is designed for the operation with the maximum pulse length of 400 μs and repetition rate up to 25 pps. It can provide at least some tens mA of total beam current, while percentage of the designed W^{4+} ions does usually not exceed 30%. Recent tests on improving of operational stability allowed to maintain stable modes of arc generator during several hours of nonstop work.

The cathode block construction gives a possibility of quick renewal of the used cathode by the enterprise operating personnel.

RFQ section

RFQ section allows to use low injection voltages of 30-35 kV with a high beam capture into the RF accelerator cavity. For the designed ions of W_{184}^{4+} the values of the limit beam current and the normalized acceptance are 6 mA and 0.25 π mm mrad correspondently. The exit energy of 27 keV/amu was chosen in accordance with the requirements of acceptable beam recapture into the prestripper APF section.

The RFQ resonator construction includes four-rod modular line with stainless pole pieces and copper support bars fixed on the resonator jacket by ceramic insulators Copper resonant spirals are tapped down between support bars and the jacket to get resonant frequency of 40.7 MHz. Electric coupling half rings provide low impedance connection between the diametrally opposing rods for decreasing of sentivity to misalignments and stabilization of the RF working mode. The cooling of the structure is furnished by distilled water which passes through spirals and support bars. The RFQ section construction include four cells which are arranged inside a common electric shell of 700 mm in diameter and 3 m long. The designed beam parameters at the RFQ section exit are the following: maximum momentum spread is 1.2%, maximum phase spread is 20°. Independent vacuum tests with a single cell of the RFQ structure demonstrated acceptable electric strength of the ceramic insulators. During one week tests under repetition rate of 25 pps and pulse length up to 400μs stable RF regimes were reached.

Prestripper Section

The prestripper section is intended for the pulse acceleration of 2 mA tungsten beam with charge +4 to the energy of 418 keV/amu. It is designed for working on an industrially permitted frequency of 40.67 MHz. The designed values of phase capture are 50° and 1.0%. A rather small momentum spread allows to consider the APF channel as a narrow bandwidth filter that prevents beam parasitic components moving to the exit. It permits to improve irradiation uniformity on the target. On the other hand, comparatively small beam intensities per one pulse are desirable to prevent the "multihole" statistic problem. At the same time acceptable productivity is reached by repeated many times (25 pps) film irradiations at different angles.

Numerical analysis of dinamics for different isotopes of tungsten showed rather high sensitivity of the APF channel to their contents. In fig.2 the longitudinal phase capture

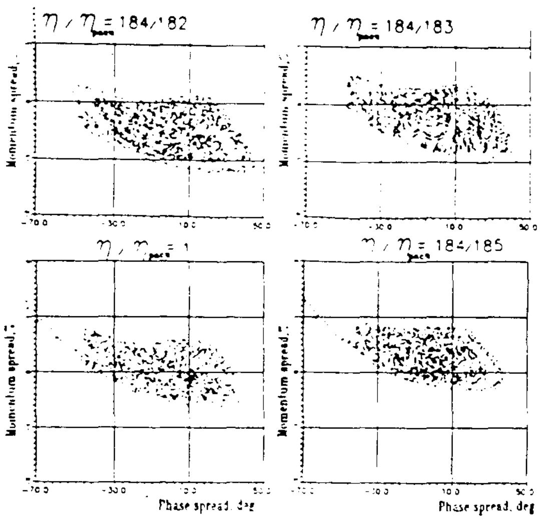

Fig. 2: Phase acceptances for tungsten isotopes

pictures for W^{4+}_{182}, W^{4+}_{183}, W^{4+}_{184} and W^{4+}_{185} for the prestripper APF section are shown. The π-mode accelerator structure of the prestripper APF section is based on a twin-line resonator with drift tubes free of any focusing lenses which are arranged in turn on both longitudinal bars. The resonator is mounted inside a copper jacket which is arranged in the stainless steel vacuum tank of 6 m long and 1.2 m in diameter. The maximum value of the field gradient in accelerating gaps does not exceed 100 kV/cm for the sake of exploitation reliability. The section contains 84 drift tubes with outer diameters from 35 mm to 70 mm and the aperture diameter of 10 mm.

The analogous construction was tested at experimental heavy ion linac that was put into operation in 1992 [4].

Stripper

We suppose to use a gas stripper to meet requirements of reliability and operating longevity for the industrial linac. A stripper chamber is arranged between pre- and poststripper sections. It is a vacuum tank of 700 mm long and 400 mm in diameter filled with the air under the pressure of 10^{-1} Torr while the working pressure in the resonators is (2-3) 10^{-6} Torr. The two-stage differential pumping will be probably used in the stripper to maintain appropriate vacuum conditions in accelerator tanks. The design equilibrium charge of tungsten ions after stripping is +16 (for about 20% of the total beam before the stripper).

The recharging gas chamber contains three cells: the central cell with a gas target and two side cells that serve for the softening of gas load to the linac structure volumes. The central and side cells are separated by diaphragmes. Every cell of the stripper and both side ends of the linac structure are furnished with their own turbomolecular pump. The total length of the stripper stage is about 1 m.

Poststripper Section

The poststripper APF section is intended for final acceleration of the tungsten beam after stripping. The design value of equilibrium beam charge is +16. Despite of principal possibility to recapture and accelerate W^{+17} ions we will hardly do it because of its negative influence on the beam formation picture at the target. So we hope to accelerate only about 20% of the beam accelerated in the prestripper section. Nevertheless, the expected intensity of tungsten ions at the target is acceptable for the chosen mode of target irradiation by repeated many time pulse beams.

The design of the prestripper section resonant structure for the working at 81.4 MHz is under discussion now. The twin-line with drift tubes design seems to be the most probable candidate because of simplicity and reliability, but we still do not exclude "interdigital" versions.

Exit Beam Formation

Of special concern is the problem of uniform irradiation field formation at the surface of polymer film of 400 mm width. This film will be transported constantly with the rate of 0.5 m/s in the transversal direction. Taking into account small (of about 2-3 cm in diameter) and essentially non-uniform beam cross-sections at the linac exit, we have a challenging problem of beam expansion and transversal equalization at the film surface.

Among different possibilities of beam formation we are considering in detail only two ways. The first approach is based on a system of multipole (quadrupole, octupole and even dodecapole) magnetic lenses arranged at the linac exit and followed by long drift pass to the target. Calculation results let us hope on successful realization of this approach. On the other hand, we are expecting some practical problems because of high sensitivity of this method to the initial beam parameters at the linac exit. Alternatively, we are considering possibilities of the circular beam scanning by use of an additional RF cavity with harmonic excitation[5].

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