30 YEARS OPERATION OF 25 MeV PROTON LINAC I-2 IN ITEP AT BEAM CURRENT OF 200-230 mA

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Abstract

The first in Russia strong-focusing 25 MeV proton linac-injector I-2, computations, design and construction of which have been carried out under the guidance of Prof. I.M.Kapchinsky, will celebrate this autumn its 30-th anniversary. Output current of the beam at energy of 25 MeV year after year is 200-230 mA, down time is less than 0.5% of schedule time of about 5000 hour/year. Launched a decade before RFQ epoch coming the linac I-2 is the "living witness" of its physical project adequation to requirements of beam dynamics and adhere to assigned stringent tolerances that determines so long machine life.

Introduction

The first in Russia strong-focusing 25 MeV proton linac I-2 was launched on November 1966. Its physical ground, design and construction were implemented by ITEP Linac Division under the direct leadership of Prof. I.M.Kapchinsky [1-4].

The purpose of the 25 MeV machine construction was to serve as an injector of the ITEP proton synchrotron (PS) and to be as a prototype of an 100 MeV injector for 70 GeV IHEP PS developed only 1 year later. The main contribution in the linac I-2 project and its implementation besides ITEP was done MRTI being the principal technology designer of RF cavities, RF supply system, RF tuning procedures, mechanics, cooling etc. and Efremov Institute (NIIEPA) which was responsible for preinjector, design of drift tubes and their dc supply. The project was performed under the general supervision of academician A.L.Mintz (MRTI) and vice-academician V.V.Vladimirsky (ITEP).

All principle decisions were carefully tested on the models and prototypes. The choice of optimum poles contour of drift tube quadrupole lenses ensures absence the sixth harmonic of the field and comparative simplicity of their manufacturing [5,6].

Very soon after the start-up the project beam current of 130 mA was achieved [7]. Beginning from 1967 till today linac I-2, being Injector the 2nd after the first 4 MV Van-de-Graaf, have continuously operated day by day delivering to PS through HEBT accelerated beam current of about 200 mA during 4500-5500 hours per each year in average [8,9].

Accurate accordance of physical I-2 project to beam dynamics requirements and its strong adhere to assigned tolerances defined the long life of the machine developed before RFQ epoch coming.

The main features of the linac design and some unusual technical decisions of its technology systems are presented.

Characteristic Features

The linac I-2 has two 148.5 MHz resonators (on 0.7-6 and 6-24.6 MeV) with 20 and 35 drift tubes containing in pairs high-current quadrupoles of opposite signs forming FOD and FOFDOD types of focusing periods. The acceleration period in the first cavity is $2\beta\lambda$; it simplified the quadrupole arrangement in tight volume of drift tubes. Note, that different acceleration periods in cavities strongly impeded later an acceleration of other ion types.

The r.m.s. error of drift tubes initial alignment is about 35 μm in transversal plane and <0.02% of the accelerating period length in the axial direction.

Drift tubes were adjusted by special alignment units on hard girders which are supported on a special long foundation that had ensured the stable conditions in spite of happened dismantle (by explosion) of one of neighbouring building and erection of the other one. The use of the developed drift tube alignment method [10] which ensure to check its positions without opening of resonators approved a good many years stability of the accelerating-focusing channel.

Both cavities of ∅1.37 m are housed in stainless steel tanks of ∅1.8 m and length of 18.4 m. At first we used 7 high throughput (8000 l/s each) oil pumps with liquid nitrogen traps and in spite of good vacuum of $3\text{-}5\cdot10^{-7}$ mm Hg rather often we suffered difficulties at RF power feeding after schedule shut-downs. The transition to 40 titanium discharge 250 l/s pumps (without of traps) ensured the working vacuum on the level of about $2\text{-}5\cdot10^{-6}$ mm Hg, but excluded almost completely multipactoring or breakdown in cavities. At this transition we replaced the ordinary gas supply system of duoplasmatron ion source by original one with exhaust valve decreasing the gas flow from 600-800 to 10 cm^3/h [11].

Note, that our cavities and vacuum tank after their closing in 1966 were never opened any more. After beginning operation with filament cathode we are using the cold cathode in duoplasmatron type ion source. Mo and Cu cold cathodes ensure their unusual long service from several weeks to more than one year [12]. The full output current is 1200-1500 mA at pulse duration up to 30 μs and average repetition rate to 1 pps. The proton component constitutes as much as 80-85%. Technological systems upgrade and matching channel redesign resulted the extreme high pulse proton current of 230 mA in 1977 year [11].

In 1984 helium ion beam current up to 300 mA has been obtained from duoplasmatron with cold cathode [13]. In checking runs He^{2+} ions have been accelerated to full energy at beam current about 2 mA [14,15]. Today the cold cathode duoplasmatron ion source with cooling upgrade is tested in CW mode at proton beam current of 10-12 mA.

The injection energy of 703 keV is adjusted by stabilized 40 kV modulator exciting the IT-800 pulse transformer that generates 700-750 kV semisinusoidal 1 ms pulses [16] with proton injection on the top of each one.

At accelerator modernization the matching channel aperture was increased up to ∅90 mm, thus restriction of transversal beam sizes occurred in the section between buncher and the first drift tube with aperture diameters of 40 mm and 20 mm, respectively. The matching channel structure simplification was achieved by using long-focusing optics properties of the accelerating column. The beam current of 420 mA at maximum phase density of 1200-1500 mA/cm·mrad is transported to the first drift tube [17]. The output beam emittance measurement showed the beam of 100 mA and more occupied always the whole channel acceptance of 1.2 cm·mrad. So, marginal value of normalized emittance for 100% particles increased in the linac channel from 0.4 cm·mrad on the input of the first drift tube to 1.2 cm·mrad at the output of the machine [18,19].

Numerous original methods and tools were developed during experimental beam dynamics investigation [20] on the linac: parametric resonance study [21], method of fixed tuning spectrometer for longitudinal oscillations frequency measurement [22], period switching-off method for transverse oscillations observation [23] etc. The set of apparatus was developed for emittance measurement at the input and output of the accelerator [24], as well as for accelerated beam RF structure observation [25].

The most noticeable failures happened during 3 decade were as follows:

- penetration of oil vapors in cavities at sudden losses of ac supply line; very slow and long time RF voltage increasing is required for burning down of that vapors;
- two destructive breakdowns of 750 kV winding isolation of HV pulse transformer; the last version of the coil has operated without failure since 1975;
- production stoppage of output power tubes GI-4A aroused a modernization of whole RF supply system based now on more powerful tubes GI-27A [26];
- failure of the last quadrupole in the matching channel placed into vacuum tank on the first cavity outer wall.

This failure threatened to a whole dismantle of the linac structure and very long shut-down of its operation. The output linac current with mismatched LEBT channel decreased to 60-65 mA that was not enough for normal injection in PS.

In order to avoid the opening up of the tank with old solidified rubber seal we insert along the axis into ∅40 mm aperture of the spoiled lens a small REC quadrupole developed in ITEP [27] with right adjusted gradient and polarity but having an inner diameter only 20 mm. It was the most simple solution. It seems to be the first experience of unclosed REC quadrupole operation in high vacuum volume of linac nearby to the proton beam [28]. Thus we restored required matching conditions and now only some more careful adjustment of the transportation through LEBT is necessary to obtain the former output beam current of 230 mA.

The output HEBT system [29,30] consists of 3 lines provided with pulse bending magnets and set of quadrupole doublets and triplets. It forms injection line with debuncher, measuring line with dc analyzing magnet and line for physical and chemical experiments, short-live radionuclide production [31] and radiation tests at 6 or 24.6 MeV (or in the air after output foil on 2 MeV less) at average proton beam current of 2 μA [32,33].

Conclusion

The linac I-2 is the very old working machine deprived modern computerized diagnostics and control apparatus but as a matter of fact due to the greatest in the world output pulse current and other good physical parameters of the beam it may be a retentive memory to the first author of the project Prof. I.M.Kapchinsky, who published a lot of papers and 4 books [34-37] devoted to analysis of the methods for obtaining high intensity ion beams. The books have played in the world the significant role in development of the ion linacs fundamental theory and engineering practice with beam currents in vicinity of the Coulomb limits.

During a time of design, construction and upgrades of the linac it has been proposed numerous inventions on original physical methods and technical solutions (partly described in the papers below) introduced in acceleration practice. They defined a good operation and reliability of the machine. Results obtained at the linac I-2 development, launching and high beam current experiments were used on the similar stages in the following strong-focusing machines in Russia.

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