BEAM FORMING SYSTEM MODERNIZATION AT THE MMF LINAC PROTON INJECTOR

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The isolation improvements of the beam forming system (BFS) of the MMF linac proton injector ion source are reported. The mean beam current and, accordingly, BFS electrode heating were increased when the MMF linac has began to operate regularly in long beam sessions with 50 Hz pulse repetition rate. That is why the BFS electrode high-voltage isolation that was made previously as two consequently and rigidly glued solid cylinder insulators has lost mechanical and electric durability. The substitution of large (160 mm) diameter cylinder insulator for four small diameter (20 mm) tubular rods has improved vacuum conditions in the space of beam forming and has allowed to operate without failures when beam currents being up to 250 mA and extraction and focusing voltage being up to 25 and 40 kV respectively. Moreover, the construction provides the opportunity of electrode axial move. The insulators are free from electrode thermal expansion mechanical efforts in a transverse direction.
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1 INTRODUCTION

The results of operation of the Moscow meson factory linac injector were previously reported at various meetings and conferences on charged particle accelerators [1-3]. Since 1992 the MMF linac regularly operates about 2000-4000 hours per year in long-lived beam sessions. The efficient linac performance substantially depends on reliable, trouble-free injector operation. In the course of routine functioning many feeble places had come to light. Among others - high-voltage isolation of the beam forming system (BFS), that was revealed when the injector mean beam current has increased. At 50 Hz pulse repetition rate (PRR) of the beam current with energy 750 keV and pulse duration 80 μs the mean current was 600 μA. Since 1998 the injector runs at 50 Hz PRR with energy 400 keV at pulse duration up to 200 μs. The mean current has increased accordingly. In the future it is supposed to increase PRR up to 100 Hz.

2 DISCUSSION AND CONSTRUCTIVE SOLUTIONS

The problem came up because of destruction of BFS isolation. As a source of protons the duoplasmatron is used. The beam is formed from wide expander ∅ 60/70mm by an extraction electrode in the form of a flat grid and by focusing electrode ∅200mm (Fig. 1). The extraction and focusing electrodes are installed at the source housing, cooled by water, initially with the help of two consequently connected cylindrical insulators of large diameter 140 mm (Fig. 1, above the axis). The insulators were stuck with the stainless steel fixture by hot-curing PVA glue. There was a backlog of insulators from the fixture in process of operation. It is supposed that because of the electrodes heating: at strong joint of steel electrodes with porcelain (coefficients of a linear thermal expansion accordingly $\alpha_{st}=12\cdot10^{-6}$ 1/degree and $\alpha_p=3\cdot10^{-6}$1/degree) porcelain when heating prevents from strain of electrodes and can be influenced upon marked stresses. Critical temperature, at which stresses reach the threshold of fracture for porcelain, is determined by a relation: $\Delta t_{cr} = \sigma_d / E_{cr}.\Delta\alpha$ [4, V.2]. At ultimate strength $\sigma_d=200\text{-}300\ kg/sm^2$, Young modulus $Ep=0.5\cdot10^6\ kg/sm^2$ and $\Delta\alpha=\alpha_{st}\text{-}\alpha_p$ it is approximately 100-120ºC. As the strength of a glue joint of insulators with the fixture was broken while fracture of insulators had not taken place, it is possible to assume, that temperature is less than critical one for porcelain (strength of a glue joint is lower than strength of porcelain).

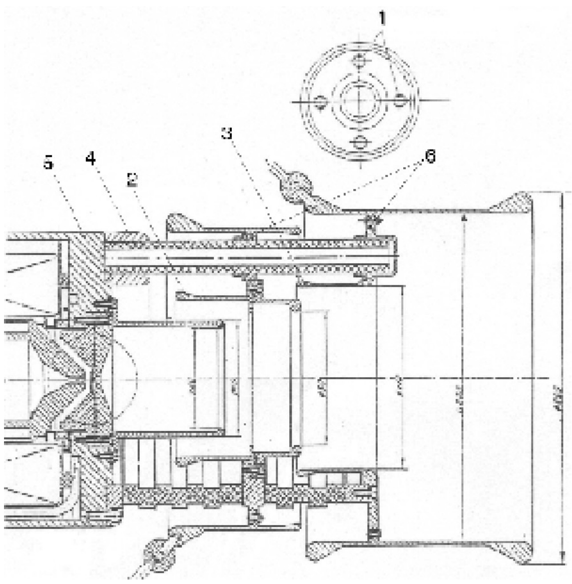

Fig. 1.

In regular injector operation mode (at rated energy) the heating of BFS electrodes is determined basically by secondary electrons flying from the accelerating tube output diaphragm (ATOD) in a direction of the ion source. The secondary electrons are caused by H^+ beam current sifting on the ATOD and walls of the beam transport channel. The gas pressure in the channel is about 10^{-4}-10^{-5} Pa, so influence of residual gas on generation of secondary electrons is negligible. A current of secondary electrons in the direction of the ion source which was evaluated following the results of measurements of beam sifting on ATOD and of gamma radiation is ~ 6 μA [5] or ~ 4.5 W of power at 750 keV.

Drain of heat from BFS electrodes depends on temperature [4] and can to occur by a thermal conduction through the insulators and by means of infrared radiation from surface of electrodes. Drain of heat by a thermal conduction through insulator (in kcal per hour): $Q_t = \lambda.\Delta T.F/L$, where the thermal conduction λ is expressed in kcal/m.h.°C, area F and length L accordingly in m^2 and m. Heat exchange by means of infrared radiation between gray bodies (in kcal per hour): $Q_L = 4.9\cdot\varphi^*_{1,2}\cdot F_1\cdot[(T_1/100)^4 - (T_2/100)^4]$, where the area F_1 - in m^2, temperature - in degrees of Kelvin, and $\varphi^*_{1,2} = 1 / [1 / \varphi_{1,2} + (1 / \varepsilon_1 - 1) + (F_1/F_2)(1 / \varepsilon_2 - 1)]$ - coefficient of mutual irradiation for gray bodies. In our case, for two coaxial cylinders with the areas F_1 and F_2, located at close distance, $1 / \varphi_{1,2} \approx 1$, $\varepsilon_1 \approx 0{,}2$, $\varepsilon_2 \approx 0.8$ and $F_1/F_2 \approx 0.5$ and $\varphi^*_{1,2} \approx \varepsilon_1$. The results of calculation are shown in Fig. 2. The horizontal dashed line (Q_e) corresponds to heat brought by secondary electrons in a regular mode (maximum value). The heat balance temperature corresponds to a cross point of dotted direct line Q_e with a curve $Q_\Sigma = Q_T + Q_L$ and does not exceed ~ 50°C.

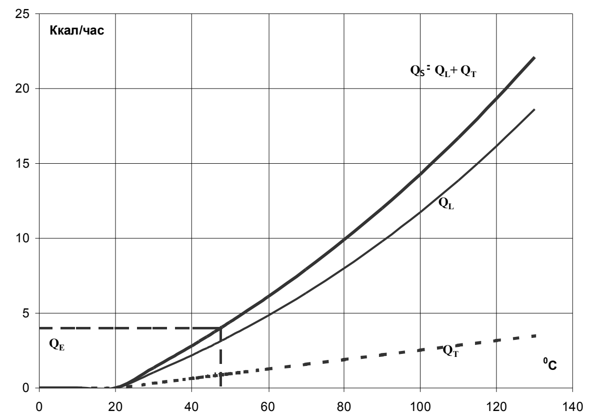

Fig. 2.

In some modes the heat flow on electrodes can be much higher, for example when accelerating voltage (AV) is increasing and the discharge of ion source is switched on, or under aging of the tube with a warming-up by a scattered beam, since at decreased AV both the sifting of the beam on ATOD and secondary electrons flow are increasing [6]. In this case the current of secondary electrons from ATOD in the direction of the ion source exceeds values for a rated mode by an order of magnitude and its power may be about tens of watts. The speed of electrodes heating is higher too. When inside the tube all things are in working order, the AV increasing occurs promptly and the dangerous mode "is slipped" imperceptibly. However transition of the injector H^+ to regular operation at a 50 Hz PRR was difficult one and was accompanied by permanent tube aging for increasing its electrical strength.

The basic problem of improvement of BFS isolation - to exclude a mechanical loading on isolation when heating the electrodes, nevertheless having maintained their position on the tube axis in tolerance limits. It was supposed that the cross travels of the extracting electrode with a grid in relation to the ion source expander and of the large diameter focusing electrode in relation to the tube electrode with a grid will appear not so critical concerning fields and beam position.

The general view of improved BFS is shown on a Fig. 1 (below the axis), fastening of electrodes - on a Fig. 3.

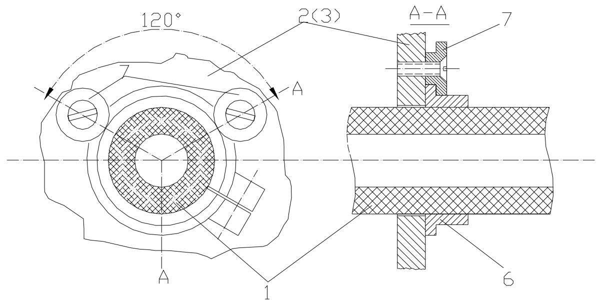

Fig. 3.

The isolation is assembled from 4 tubular rods (1) ∅ 20/5/170 mm (from radioporcelain GB-7), which past through extraction (2) and focusing (3) electrodes. The rods are rigidly anchored by the cantilever at basic flange (4). The fastening of basic flange (4) to a housing of the ion source (5) is made on the fit flange by 4 screws after assembly of construction on an assembly table.

The rods pass through extraction (2) and focusing (3) electrodes with a clearance 0.5-0.6 mm. The position of electrodes along the tube axis is determined by clamps (6), which are rigidly fixed on the rods. The electrodes fasten to each clamp by two profile washers (7) from the external part of the rod in relation to the axis of the system. The axial symmetry is sustained with accuracy to within 0.1 mm. At heating such assembly is expanded outside from the insulating rod with slide along fastening washers, forming a radial clearance about 0.1 mm/100°C. On a ∅20 mm clamp a clearance approximately 0.015 mm will appear too. At a horizontal working position of BFS electrodes such values are permissible.

3 CONCLUSION

Improved BFS has designed in a supposition, that the thermal factor plays the basic role in fractures of isolation. The suppositions were expressed too, that the fractures of insulators can be associated with possible large electrodynamic loadings on insulators at disruptions, because the fractures were always accompanied by disruptions but there is no precise model. After replacement of BFS insulators breakdowns took place, but fractures were not fixed any more. No influence on the beam position, in connection with possible thermal travel of BFS electrodes across an axis, was marked. Any weakening of mechanical fastening of electrodes to insulator were not observed.

One of improved BFS advantages is an appeared opportunity of electrodes travel along the axis. Length of rods can be increased if necessary. The ends of the rods in the region of the electrodes should be closed with metal caps with galvanic connection with the electrode in order to prevent accumulation of charges and field distortion. In process of designing it was supposed to use an opportunity of BFS electrodes travel along the axis for correction of optics in the case of 400 kV injection voltage.

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