MESON FACTORY INJECTOR COMPLEX

by

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In the USSR the meson factory is under development which, like the Los Alamos Meson Facility,[1,2] consists of a high-current linac.

The Meson Factory Injector complex (MFIC) should provide ion beams at the input of the drift tube, having the following parameters:

1. Ion energy	750 KeV
2. Ion energy stability	± 0.1 %
3. Pulse current	
a) of protons	150 mA
b) of hydrogen negative ions	10 mA
c) of hydrogen negative polarized ions	0.1 mA
4. Pulse duration	120 msec
5. Pulse repetition rate	100 Hz
6. Simultaneous injection of two beams	
a) either protons and negative ions, or	
b) protons and polarized negative ions	
7. Normalized emittance of two simultaneous beams	0.15 π cm·mrad

The general layout of the injector complex was made on the basis of the following requirements:

1. Necessity of simultaneous injection of two beams in the linac.

2. Transport of high-intensity proton beam and negative ion beams should be effected in separate ion-optical channels, and the common length of each channel should be minimum.

3. The number of bending magnets as well as the effective angle of bend of beams should be minimum.

4. Independent maintenance of injectors.

5. Provision of sufficient electric strength.

The drawing of the MFIC general layout is given in Fig. 1.

The length of the transport system is connected with the dimensions of high-voltage gaps and high-voltage devices.

For all injectors a pulse transformer having a stabilization system of pulse top is used as a source of accelerating voltage.

Principal solutions of the high-voltage supply system were tested on a model at 500 kV. The power supply system of the ion source is located in a special box at a high potential. The primary voltage is fed through the pulse transformer secondary winding to the ion source power supply system.

All injectors of the meson factory use an open type acceleration tube of glued porcelain insulators 50mm high. Internal electrodes, exciting the field in the acceleration region, are made of titanium. The length of the acceleration tube is 1.5m. On the external surface of the tube a water resistance divider is placed on gradient rings.

The vacuum system employs magnet-discharge and turbo-molecular pumps with a pumping speed of 1000-5000 l/sec.

The ion-optical system of MFIC should provide the passage of H^+ and H^- ion beams from the ion sources to the input of the linac without essential losses, with minimum growth of effective emittance of the beams.

The most complicated problem is that of transporting the intense flux of negative ions. Let us consider this problem in more detail.

The beam divergence under the action of its space charge in a length equal to the period of focusing system, S, is defined by a known equation,

$$f\left(\frac{R}{R_0}\right) = \sqrt{\frac{2I}{\beta^3\gamma^3 I_0}}\ \frac{S}{R R_0} \tag{1}$$

where R, R_0 are the final and initial radii of the beam, I is the beam current, $I_0 = 3.14 \times 10^7$ A. Assume that the action of Coulomb forces is small if the relation $R/R_0 \leq 0.2$. Then from (1) we obtain that the action of the space charge can be neglected, if

$$R \geqslant \frac{3S}{\sqrt{2}\,\beta^{3/2}\gamma^{3/2} I^{1/2}}\sqrt{I} \tag{2}$$

is satisfied.

The beams with finite phase volume have one more criterion, characterizing the measure of the space charge action. This is the so-called Coulomb parameter of the beam[3]:

$$h = \frac{I}{\beta^3\gamma^3 I_0 E}\ \frac{R^2}{\sqrt{R^2 + \frac{\beta^3\gamma^3 I_0 E^2}{2I}}}, \tag{3}$$

where E is the beam emittance. If $h \ll 1$, then the dynamics of particles in the beam will be defined by the phase volume and external focusing fields. Let us consider that h is sufficiently small, if $h \leq 0.2$.

Then from (3) we obtain that the action of Coulomb forces will be small compared to that due to velocity spread and phase volume if the condition

$$R \leqslant \frac{\beta^{3/2}\gamma^{3/2} I^{1/2}}{\sqrt{2}}\ \frac{E}{\sqrt{I}} \tag{4}$$

is satisfied.

In the derivation of formula (4) it is assumed that the beam is in the external focusing field, chosen so that at given values of I, E, R, the accepted conditions are satisfied. It is from (4) that, at small radii of the beam in spite of the decrease of space charge density, the relative action of Coulomb forces (compared to that of velocity spread and focusing fields) is small.

Curves, defined by Eqs. (1) (curves R_2, R_3) and (4) (curve R_1), are shown in Fig. 2. The curve R_2 corresponds to a period of focusing structure, S = 1m, and the curve, R_3, corresponds to S = 0.12m. Shaded regions correspond to beam parameters at which the action of Coulomb forces is significant. It is seen from Fig. 2 that at beam currents of the order of 100-200 mA and at S = 0.12m the action of Coulomb forces is not large. S = 0.12m corresponds to the period of focusing structure for the initial part of the linac. For the injector transport channel, due to the necessity of locating auxiliary equipment, S is taken to be 1 m at the present stage of designing.

The question of optimal S will be discussed in more detail. In our case, as seen from Fig. 2, the action of Coulomb forces will be small either at beam radii much greater than 2 cm, which is objectionable due to the necessity of a considerable increase of ion tube equipment, or at values of R of the order of 1-2 mm. These values of the beam radius are unreal in our case, since because of velocity spread of particles, the beam at a distance of 1 m will rapidly diverge. Therefore, when the beam passes through the injector complex transport channel, the action of Coulomb forces will be inevitably large. In particular, certain distortions of phase volume are possible. In the linac itself, as seen from Fig. 2, phase volume distortions practically should not take place. It follows that basic distortions of the beam phase volume will take place in the transport channel.

Numerical studies of the transport of intense beams for various types of focusing structure have been made.[4] These studies have shown that, in the case of intense beams having finite phase volume, focusing by axisymmetric lenses is the most effective. Firstly, the beam can be transmitted through an axisymmetric system at smaller apertures of lenses than in the case of quadrupole focusing system. Secondly, in the axisymmetric case the effective emittance growth is much lower (see Fig. 3). Besides, it should be mentioned that the axisymmetric system is more flexible and convenient from the viewpoint of changing and adjusting different regimes, while the quadrupole system has a very narrow range of optimal gradient.

These studies have also shown that an axisymmetric system combined with one quadrupole lens at the matching channel exit can provide an agreement between the beam emittance and the linac acceptance not worse than the quadrupole lens system. The thing is that at large values of the current and the beam phase volume the quadrupole systems also cannot provide an ideal agreement. For the same reason the application of axisymmetric lenses combined with bending magnets, focusing only in one plane, should not present additional problems with the beam agreement. Nevertheless, the application of bending magnets with double focusing will be discussed.

The normalized emittance at the ion source exit was calculated to be 0.5 π cm·mrad. Considering the growth of the beam emittance in the presently chosen transporting channel at the entry of the linac, emittance will be of the order of 0.3 π cm·mrad. This value exceeds the required emittance. To the required emittance there corresponds a part of the beam with a current of the order of 50 mA.

The problem of transmitting and focusing the negative low-current beams is less complicated. The problem of the simultaneous transmission of positive and negative beams through the matching channel should be studied in more detail. Preliminary theoretical studies show that this problem is solvable.

As a positive ion source the duoplasmatron previously developed at D.V. Efremov Scientific Research Institute of Electrophysical Apparatus is used . However, to provide the required parameters of the beam at the linac entry the improvement of the extraction region of ions is being conducted with an aim to increase the phase density and to obtain minimum distortions of phase volume configuration.

At the first stage, the ion-optical system of the ion source and acceleration tube is similar to the optics of the preinjector of the Serpukhov accelerator, which proved to be good[5]. But the developed tube construction allows one to check other versions of optics at the stage of experimental debugging. In particular, a version of an accelerating system with constant electric-field gradient and without preliminary focusing devices will be checked.

It is shown theoretically[6] that accelerating systems without preliminary focusing give much smaller distortions of the beam transverse phase volume than those with preliminary focusing. This is connected with the fact that acceleration time in the first case can be considerably shorter, and, in consequence, the relative action of coulomb forces is smaller.

The high-vacuum pumping of the positive ion injector is accomplished by four magnet-discharge pumps. At continuous flow rate of gas into the source, the pressure at the acceleration tube exit will be 5×10^{-6} torr.

An adjustment device provides the adjustment of the ion source together with the acceleration tube.

The negative injector (Fig. 4) employs as a negative ion source a source with tubular discharge and with ion extraction from the internal region of discharge[7].

For reducing the negative ion losses due to charge exchange during the formation and acceleration of the beam, this injector employs, besides four magnet-discharge pumps (like the positive ion injector), a turbomolecular pump, by means of which the volume in front of the acceleration tube entry is pumped out through the insulator.

The source of negative polarized ions is based on a method of atomic beam separation in a nonuniform magnetic field by energetic states of fine structure with subsequent change into an energetic state of one of the levels of hyperfine structure, of ionization in a magnetic field and cesium vapor charge exchange into negative polarized ions. A model of the polarized ion source is under laboratory tests[8]. The polarized ion source is located at a potential of 750 kV. In this connection the pumping-out should be accomplished by four magnet-discharge pumps, located also at the high potential, and by the turbomolecular pump through the insulator. At the acceleration tube exit one magnet-discharge pump is mounted.

The MFIC ion tube is placed on adjustment benches. The distance covered by the beam from the injector exit to the linac entry is 10.7 m. The ion tube inner diameter is 60 mm. Along the transport channel the ion tube bending magnets, axisymmetric magnetic lens, measuring systems of beam parameters, forming devices of beam pulses and magnetic corrector are placed. The matching channel consists of the axisymmetric magnetic lens, buncher and quadrupole lens. On each branch of the ion tube and at input of the linear accelerator the magnet-discharge pumps are mounted.

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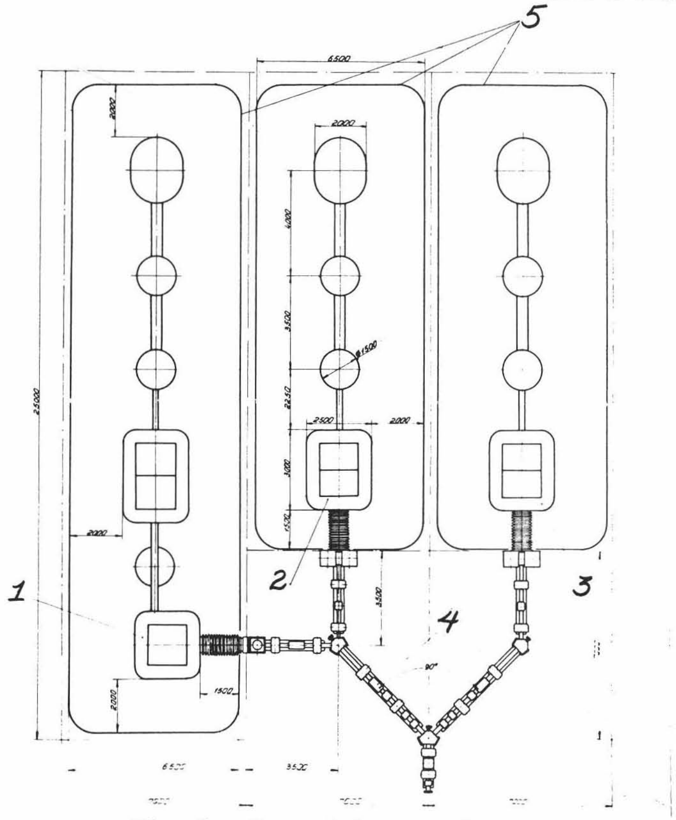

Fig. 1. General layout of MFIC.

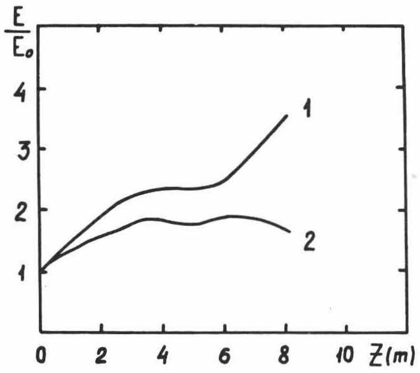

Fig. 3. The growth of effective emittance of proton beam in transport channel; 1) quadrupole focusing system; 2) axisymmetric focusing system.

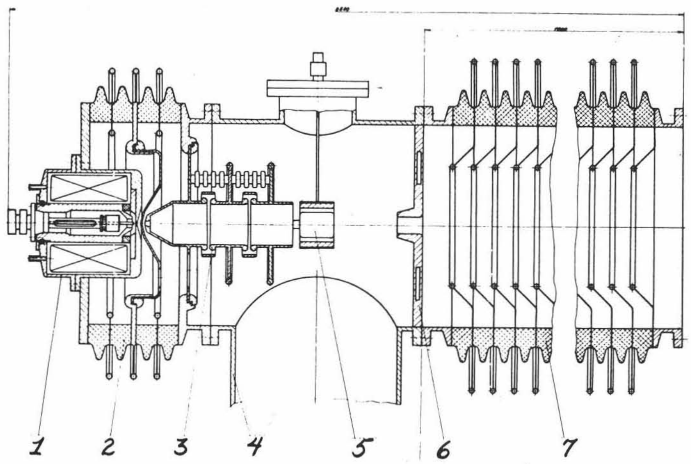

Fig. 4. Negative ion injector.

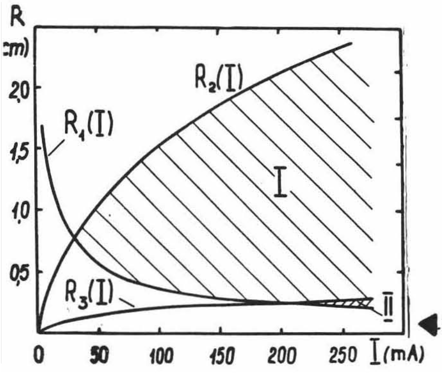

Fig. 2. Diagrams for definition of regions under the strong action of Coulomb forces.