CHOICE OF THE BLOCK - SCHEME OF 1-1.5 GeV 300 mA LINEAR ACCELERATOR

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The consideration of some questions related to design of 1-1.5 GeV proton linac is associated with the efforts to solve fuel cycle long-lived radioactive waste management problems.

The proposed linac consists of three parts:

1. Initial part comprising electrostatic injector and 3-5 MeV RFQ;
2. Middle part providing acceleration up to the energy of 100-150 MeV;
3. Main part, where protons reach the energy of 1-1.5 GeV.

Accelerating and focusing structures of each part are characterized by its own range of particle velocity changes, where the parameters of acceleration and focusing are optimized:

Initial part	β = 0.0080 - 0.10
Middle part	β = 0.080 - 0.50
Main part	β = 0.40 - 0.92

In the initial part the electrostatic injector voltage must be sufficiently low in order to provide the necessary margin of electric strength of accelerating tube at 100% duty factor.

Historically the first main part of high energy proton accelerator was designed in Los Alamos for meson factory[1]. The structure comprised the sequence of one-gap side-coupled resonators. But now many scientists consider the disc and washer structure proposed by V.G.Andreev (Moscow Radiotechnical Institute)[2] and designed for INR meson factory to be the best. This structure is characterized by the most wide dispersion and the most high shunt impedance. Disk and washer structure in some of its modifications is in fact being the only used today.

For the middle part of the linac three types of accelerating structures can be considered:

1. H-structure with alternate phase focusing;
2. H-structure with periodic RF quadrupoles;
3. E-structure (Alvarez tank) where the beam is focused by rare-earth magnet quadrupoles.

First type of structure was proposed in 1956 by Ya.B.Fainberg (Kharkov Institute)[3] and then subsequently modified by V.V.Kushin (Moscow Radiotechnical Institute)[4a] and N.A.Khizhnjac (Kharkov Institute)[5]. Such structures are being developed in ITEP[4b] and Kharkov Institute. The second type of structure was proposed in 1956 by V.V.Vladimirskiy (ITEP)[6] and then subsequently modified and manufactured by V.A.Tepljakov (Serpukhov Institute); such structures are being developed and operated in Serpukhov Institute[7]. As concerns the third type of structure, the focusing of particles by rare-earth magnet quadrupoles was proposed simultaneously and independently in 1979 by K.Halbach[8] and a group of ITEP scientists (I.M.Kapchinskiy, N.V.Lazarev and V.S.Skachkov)[9,10]. Rare-earth magnet quadrupoles are being developed in ITEP and in a number of scientific centers abroad.

Alternating phase focusing (APF) is obviously not suitable for high current linear accelerators. As is known, the main advantages of this structure are cheapness and technological simplicity that enables to use it successfully for applied linacs with low pulse currents and relatively low energy, especially when high acceleration rate is needed. Nevertheless such disadvantages as low capture, low current limit and the trend to decreasing of shunt impedance as the particles velocity increase prevent to use it for large linacs.

The structure with spatially periodic RF quadrupoles (with so called "horned" electrodes) is free from disadvantages typical for APF structures. This structure was successfully used in the injector to Serpukhov proton synchrotron booster[11]. Nevertheless, the use of the structure in 100% duty factor high current linac is not justified due to the difficulties in structure cooling, reduced margin of electric strength and impossibility to chose independently the parameters of longitudinal and transverse motions.

It seems to us that DTL with rare-earth magnet quadrupoles is the most suitable for the middle part of high current linac. The advantages of Alvarez linac such as constancy of acceleration rate along the structure, high mean acceleration rate, relative simplicity of cooling and practically constant value of shunt impedance along the structure are well known. Use of rare-earth magnet quadrupoles substantially increase the radiation resistance of the linac compared with the linac equipped with electromagnetic quadrupoles. Rare-earth magnets don't release heat and don't need stabilized power supply systems, this obstacle solves the same problem which initiated the development of RF focusing methods. It should be mentioned that use of rare-earth magnet lenses allows to decrease the drift tube dimentions and hence to reduce RF losses and in necessary cases to open the way for substantial increase of accelerating field frequency. The disadvantages of this structure are its relative expensiveness and technological complexity. However for large linear accelerators these disadvantages are not so important.

In the initial part of the linac it is necessary first of all to provide rather high rigidity of focusing at low particle velocities. Compact RF structures with solenoidal focusing and RFQ structures satisfy this condition. Solenoidal focusing practically withdraw limitations on beam current caused by transversal Coulomb repulsion because the frequency of transversal oscillations can be infinitely increased. The magnetic field should be very high that is why only superconducting solenoids can be used. At given aperture the current limit is increasing by a factor of 10 at field strength of 5 T and by a factor of 40 at 10 T compared with alternating-sign focusing (the assesment was made not taking into consideration possible instability of beam envelope). In case of solenoidal focusing the limitations are associated mainly with longitudinal Coulomb repulsion. The effect of longitudinal repulsion can be mitigated if the equilibrium phase is rather high. It makes the use of superconducting solenoids in low energy high current accelerators very attractive. As concerns the use of solenoidal focusing in the initial part of large high current accelerator, in our opinion it is not justified because the substantial difference between the transversal oscillations frequencies in the initial and subsequent parts of the linac makes the matching very complicated or even practically impossible. Criogenic facility needed for superconducting solenoid of the initial part reduces the reliability of large linac as a whole and makes the operation very complicated.

The implementation of RFQ structure in the initial part allows to use rather low voltage electrostatic injector and provides practically full capture of particles produced by the ion source into acceleration. These two features are the most important for 100% duty factor high current accelerator. The methods of beam matching in case of RF focusing are well developed and proved at the operating facilities. In order to minimize beam losses the acceptance of 100% duty factor high current accelerator should have sufficient margin. This task can be solved in view of recent developments. The funneling scheme proposed in USA allows to sum the beams without the increase of phase volumes and peak currents[12,13]. In particular the initial part can have two accelerating channels, each of them being connected to its own ion source. The number of accelerating channels can be increased if necessary. Such a structure is called "tree-like". Thus, in our opinion the optimum block-scheme of 100% duty factor high current linear accelerator should comprise RFQ as the initial part, Alvarez tank with rare-earth magnet quadrupoles as the middle part and the Andreev's structure (DAW) as the main part. The main parameters of such 1.5 GeV linac are presented in another report submitted to this Conference[14].

Indirect confirmation of the validity of such a scheme is illustrated by the fact that many scientific centers (in USSR,USA,FRG and Japan) are widely use it as a whole or by parts[15-17].

The choice of radio frequency for each part is determined by three conditions: provision of enough acceptance margin for given emittance and beam current; provision of beam funneling; provision of beam overcapture without particle losses at beam transfer from one part to another.

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