ELECTRON BEAM MONOCHROMATIZATION IN THE LINAC USED AS AN INJECTOR TO THE STRETCHER

P.I. Gladkikh, A.N. Dovbnya, Yu.D. Tur, V.A. Shendrik and A.A. Shcherbakov

Kharkov Institute of Physics and Technology, Ukrainian SSR Academy of Sciences, 310108 Kharkov, USSR

Abstract

The Kharkov electron linac is currently under reconstruction to be used as an injector for the stretcher ring/1/. The expected energy decrease due to the beam load is 600 MeV at a pulsed current of 200 mA. Therefore for the beam monochromatization a combined system is being developed which includes a time-delay means /2/ , a compensating section and an RF compressor at the exit of the linac. This system will permit the energy spread caused by the beam loading during the pulse and the accelerating field variations, to be reduced from 600 MeV to 3 MeV. This report presents the calculations of the system.

Introduction

The reconstruction of the 2 GeV linac is in progress. New accelerating sections installed in the linac have the beam loading derivative of 65 MeV/A and the filling time of 1 μs. The injected beam pulse will be 1.4 μs. Thus a large fraction of the beam will be accelerated during the transient operation of the accelerating sections. The beam transport system is designed to provide an achromatic beam transport within the range $\Delta E/E = \pm 1\%$. The beam losses in the transport system are 10^{-3} corresponding to a permissible radiation level in the experiments. Preliminary calculations have shown the time-delay procedure /2/alone to be insufficient to make up for the energy spread per pulse all over the range of the beam current in the linac. The developed scheme of the beam monochromatization includes i) a time control system for RF power input into the accelerating sections with the spectrum compression coefficient of 8 (ΔE_{in}= 600 MeV, ΔE_{out}=75MeV), ii) a special section in the recuperation ring with the adjustable coefficient of power branching-off to the input, the spectrum compression coefficient being greater than 3 (ΔE_{in}= 78 MeV, ΔE_{out}= 25 MeV), iii) a beam compressor in combination with an achromatic debuncher (ΔE_{in}= 35 MeV, ΔE_{out}= 3 MeV).

Time Delay Procedure

Fig. 1 shows beam spectra at the exit of the uniform-structure 2 GeV linac which has the beam loading derivative of 28 MeV/A. Without the use of the time-delay the spectrum broadens to 100 MeV at the current of 73 mA for a final energy of 1800 MeV ($\Delta E/E$ = 6 %). In the new quasi-constant gradient sections with 65 MeV/A this effect will be a factor of 2.5 stronger. In our new accelerating sections, as in constant-gradient sections, the beam energy during the pulse is described by

$$W(t') = [PR_oL/(1-e^{-2\tau})]^{1/2}[1-e^{-2\tau(t'+t'_o)}] - JR_oL[(1-e^{-2\tau}2\tau t'-e^{-2\tau t'})/2(1-e^{-2\tau})], \qquad (1)$$

where $t'=t/t_f$, t is the real time $0 \le t \le \tau_B$, τ_B is the beam pulse width, $t_f = \frac{2Q\tau}{\omega}$ is the filling time, P is the input RF power, R_o is the shunt impedance, τ is the damping, $t'_o = t_o/t_f$, t_o is the beam pulse delay with respect to the RF pulse, and J is the beam current.

The total beam energy is a sum of contributions from all the sections and is expressed as

$$E(t') = \sum_{j=1}^{N} W(t', t'_{oj}, R_{oj}, P_j, \tau_j) \qquad (2)$$

where N is the total number of the accelerating sections and j is the dummy index.

It is rather easy to find the optimum (minimum) energy spread and choose an individual time delay for each section to provide a required beam energy spread better than $\pm 1\%$ at the exit of the linac for a given current. In this case ,however, we are faced with stringent requirements on the time jitter

($\Delta\tau_{B\gamma}$ = ±1 ns)of the beam pulse relative to the RF pulse in the section. At the same time, the actual time spread of the klystron pulses due to the thyratron anode delayed time jitter is ±10 ns with a time drift of 100 ns. For convenient operation and fast on-line control in transition to another pulsed-current mode it is desirable to provide necessary adjustment with a small number of delays. To reduce the contribution of the chromatic aberrations to the transverse beam emittance the energy spread should be compensated for as the beam passes through the accelerating structure.

The beam energy spread was calculated by the formula (2) taking into account the pulse shape variation. As was revealed by the calculations, it is quite sufficient to have four sets of adjustable time delays for energizing the klystrons of which two time delays should be constant ($0, t_f$) to provide the beam energy spread at the linac exit below 75 MeV for the beam current to 200 mA.

Fig. 2 shows the beam energy variation at the output of each sector (one sector comprises 10 accelerating sections) for a pulsed current of 200 mA with a pulse width of 1.4 μs.

Compensating Section

A fine adjustment of the beam energy will be performed by the last section compensating for the energy spread. The beam energy gain in this section almost completely eliminates the time dependence within the pulse width. After analyzing a variety of accelerating structures we concluded that in our case the most suitable is a constant-impedance 3-m section (a/λ =0.14) with the filling time of 0.26μs. The section is enclosed in the recuperation ring with an adjustable coupling coefficient permitting the efficient filling time to be controlled in the range from 0.25 to 1μs. The time of the pulsed power input into this section and the time delay are adjusted by PIN-diode switches.

The compensating section will be most useful for the injection into the stretcher at lower energies (0.5 to 1.5 GeV). As can be seen in fig. 2, under these operating conditions, the compensator can reduce the energy spread from 32 to 15 MeV.

Beam Compressor

It is planned to carry out the monochromatization of the beam with energy spread of ± 1% using a high-frequency compressor mounted immediately in the beam transport system. Fig. 3 shows a layout of the initial part of the beam transport system combined with the compressor. The parameters of the transport system meet the requirements for the transverse beam optics, simultaneously providing a desired longitudinal dispersion $\mathcal{D}$= 66 deg/per cent. The compressor parameters were chosen taking into account the beam loading and the energy spread ΔE= ±30 MeV compensated for in the initial ± 5°- bunch. The required energy gain and the bunch phase with respect to the wave in the steadily operating compressor are determined from the expressions

$$W_0 = \left[(\Delta E/\sin\theta)^2 + (JA)^2\right]^{1/2}$$
$$\cos\varphi = JA/W_0 \qquad (3)$$

with
$$A = \frac{R_0 L}{\tau}\,\frac{\sin\theta}{\theta}\left(\tau + e^{-\tau} - 1\right),$$
$$\theta = \mathcal{D}\Delta E/E$$

Under transient operating conditions ($t \le t_f$) the energy spread is only partially compensated for in the compressor. To reduce this effect the compressing section has a uniform structure with a/λ = 0.14 and filling time t_f = 0.38μs. The additional spectrum broadening for this section will not exceed 0.15% for the current of 200 mA in the transient operation (0 ÷ 0.38μs). Fig. 4 represents the beam spectrum and phase distribution at the compressor output.

Conclusions

The monochromatization scheme proposed permits the beam loss to be practically avoided in the beam transport system and to obtain a beam with energy spread of 0.1 % at the stretcher input.

Acknowledgement

The authors acknowledge the interesting

and useful discussions with Dr. I.M.Karnaukhov.

References

1. V.F. Boldyshev, P.I. Gladkikh, V.Yu. Gonchar et al., Trudy XIII Mezhdunarodnoj konferentsii po uskoritelyam zaryazhennykh chastits vysokikh ehnergij (Novosibirsk, 1986) Nauka Publ.,1987, p.300-303.
2. R.B. Neal, The Stanford two-mile accelerator, W.A. Benjamin Inc, 1968, p.86

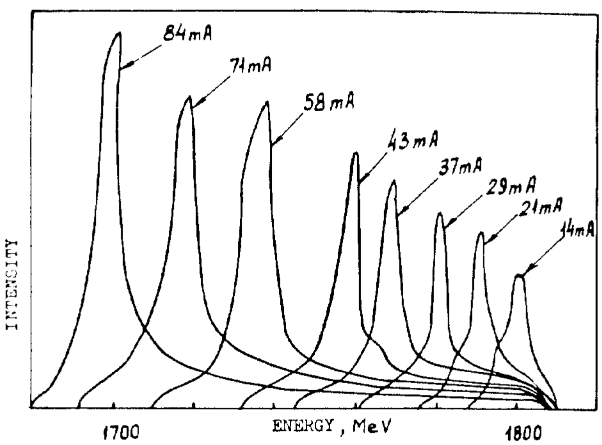

Fig.1 Energy spectra at the linac exit under different beam loading conditions.

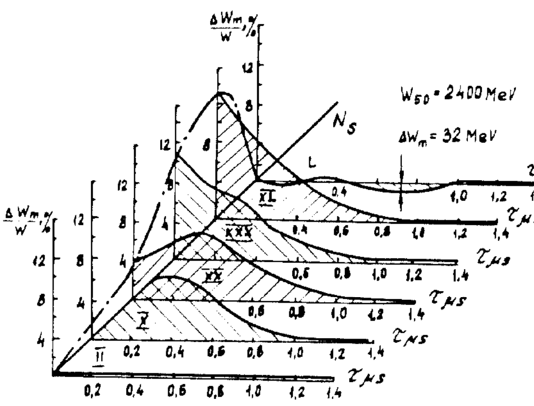

Fig.2 Energy spectra along the length of the linac for time delays: t'_o = 0.64 (N_s= 1...15), t'_o = 1 (N_s= 16...43), t'_o= 0 (N_s= 44...50); N_s : number of sections; I = 200 mA.

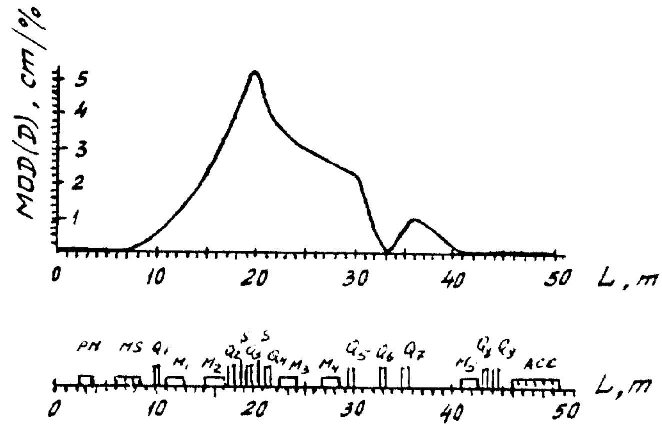

Fig.3 General layout of the E.G.S. PM:pulsed magnet, M_1...M_5: dipole magnets, Q_1... Q_3: quadrupoles, S: sextupoles, MS: septum, ACC: accelerating section D: dispersion function, L: distance.

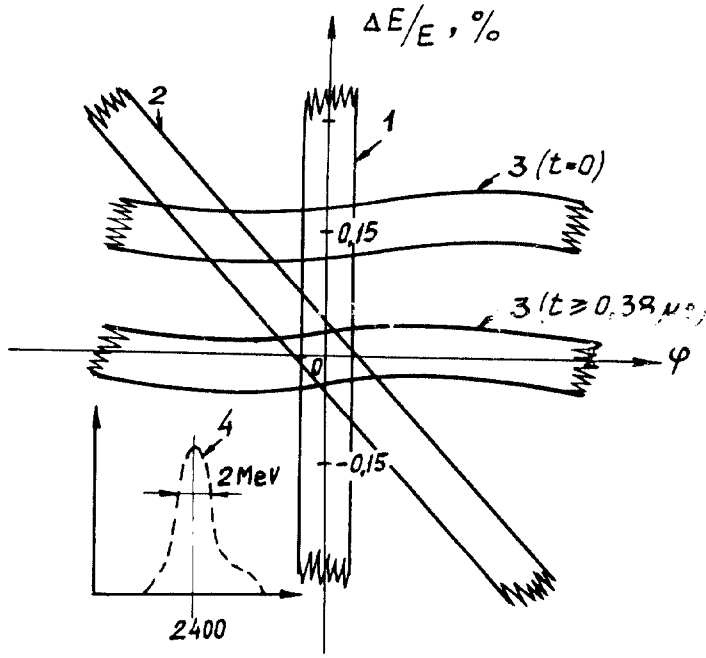

Fig.4 Phase space transformations. 1,2,3: bunch phase pictures at the exit of the linac, magnetic debuncher and RF compressor, respectively, 4: energy spectra.