Selective Method of Maximum Current Increasing in Electron LINACs

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Abstract

The beam current is limited in high beam loading science and technology electron LINACs because pulse shorting effect. Selective methods of the struggle with this effect are most effective. They consist in parasitic modes oscillation damping.

1. BEAM SHORTENING EFFECT DAMPING METHODS

The beam shortening effect is well known. This effect for one accelerating section consists in the appearance of the electron beam exited oscillation of higher-order modes with one azimuth variation, maximum radial magnetic field H_r and minimum longitudinal electric field E_z on the accelerating structure axis. The deviated beam, interacting with E_Z component of higher-order mode, excites it in additional. The H_z component deviates the beam still more. The beam finds oneself in higher E_z field and excites this mode still more.

The radial deviation of the beam is accumulated in the polysectional accelerating system from section to section. Finally the beam gets the high radial deviation and are lost on the accelerating system walls.

The parasitic modes of disk-loaded waveguide are analogous to E_{1n0}-modes of cylindrical resonator. The analogous modes can be excited in the RF-structures of more complex form, for example, polycylindrical or polydisc resonators [1] and in the induction accelerators [2].

As the research shows [3,4], the maximum beam current

$$I_{max} = \frac{k\lambda_{1n}^{3} W}{L^{3} R_{t}^{2}} \qquad (1)$$

where k - constant coefficient,

λ_{1n} - parasitic mode wave length,

W - electron kinetic energy,

L - accelerating section length,

R_t - transverse shunt impedance.

The following methods of the struggle with beam shortening effect are known:

- manufacturing of radial splits in walls between coupled resonators;
- decreasing of accelerating section length;
- increasing of wave length;
- decreasing of parasitic modes transverse shunt impedance.

The radial splits create the additional coupling between cells and make difficult the higher-order modes excitation. Decreasing of the accelerating section length may be reached by means of increasing of acceleration rate at the expense of increasing of the RF-power or using of the polysectional accelerating system. The operation and higher-order modes frequencies are correlated usually. Therefore decreasing of the higher-order mode frequency results in decreasing of the operation frequency. Decreasing of the parasitic mode shunt impedance is realized by means of bringing of the absorber into the accelerating cavity, for example ferrite [2] or Al-Si-Fe cover. The absorber may be disposed in accelerating cavity directly or in the special absorbing resonant cavity, tuned on the parasitic mode frequency and coupled with accelerating system cavity [5]. In last case RF-power absorption takes place with parasitic mode frequency only.

The demerit of split method is increasing of breakdown possibility , as radial splits are disposed in the high electric field region of the operation mode. The creation of polysectional accelerating system leads to complication of RF-feeding system and construction on the whole. The wave length increasing leads to high dimensions of the accelerating and RF-feeding systems. Bringing of the absorber into the accelerating cavity decreases both the parasitic mode transverse shunt impedance and the operation mode longitudinal shunt impedance. In this case acceleration efficiency decreases.

More effective methods of struggle with the pulse shortening effect are selective methods. One of them is mentioned above and consists in coupling of special absorbing resonator with accelerating system. The second method uses ferromagnetic resonance effect.

2. RESONANT DAMPING METHOD

Resonant damping method may be realized by several ways. Firstly, the quarter-wave coaxial resonator with absorbing cover (for example Al-Si-Fe), tuned on the parasitic mode frequency, may be coupled with accelerating cavity by means of capacitative or loop coupler, as it is suggested in [5] (see Fig.1 a and b). The resonator length with capacitative coupler is equal to $\lambda_{1n}/(1/4+\boldsymbol{m}/2)$ and with loop coupler - $\lambda_{1n}/(1/2+\boldsymbol{m}/2)$, where $\boldsymbol{m}$ - 0, 1, 2, ...

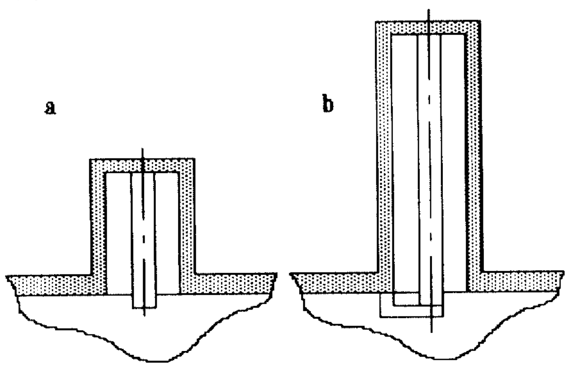

Figure 1. The coaxial absorbing resonator, coupling with accelerating system cavity by means of capacitative (a) or loop (b) coupler.

The other realization of this method is shown on Fig.2. The cylindrical resonator with absorbing cover has operating E_{010}-mode. It is coupled with the last cell of disk-loaded waveguide and tuned on its parasitic mode frequency. The absorbing resonator has high coupling value with accelerating system on the parasitic mode frequency and is not coupled on operation frequency. It guarantees the selective absorption of the RF-power on the parasitic mode frequency only.

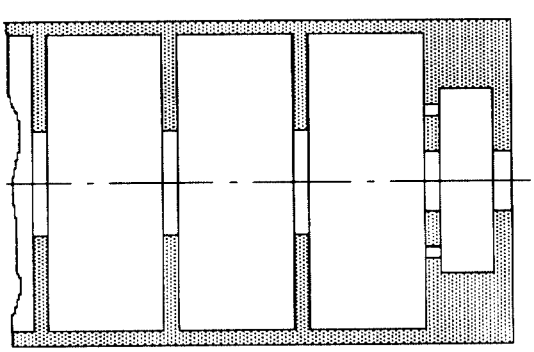

Figure 2. The cylindrical absorbing resonator, coupling with accelerating system cavity by means of the holes in the common wall.

It is useful to note, that the choice of the coupling value of absorbing resonator with accelerating system is the crucial procedure. The incorrect choice of coupling between absorbing resonator and the last of cell of disk-loaded waveguide leads to the appearance of reflection of parasitic wave from absorbing resonator and therefore to low efficiency of parasitic mode damping. It is worth while the coupling value of the absorbing resonator with the last of cell of disk-loaded waveguide is equal approximately to cell-to-cell coupling in the disk-loaded waveguide parasitic mode passband.

3. FERROMAGNETIC RESONANCE METHOD

The second selective method of struggle with pulse shortening effect uses ferromagnetic resonance effect. For the realization of this method one or several ferrite plates are disposed in the accelerating system cavity and fixed on the cavity walls in the parasitic mode magnetic field region. The windings of magnetic system are disposed on the outside of the accelerating cavity and provide with the constant magnetic field $\boldsymbol{H_0}$ on the ferrite plates , corresponding to the resonant absorption of RF-power on the parasitic mode frequency:

$$H_0 = \frac{g}{f_0} \tag{2}$$

where f_0 - parasitic mode frequency, MHz;

g=35 10^{-3} MHz m/A - gyromagnetic coefficient.

The parasitic wave excited by electron beam travels from the accelerating system axis in radial direction. The parasitic mode oscillation in the accelerating gap may be considered as the impinging and back one azimuth variation electromagnetic waves traveling in radial line between the axis region and the shorted periphery part of the cell. Therefore, there are the points in the cell cavity corresponding to the ring polarization of the magnetic field for the impinging or back wave. The fixing of the ferrite plates in these points and creating of the magnetic field $\boldsymbol{H_0}$ provide the resonant absorption of RF-power on the parasitic mode frequency and decreasing of the transverse shunt impedance $\boldsymbol{R_t}$. The dependence of $\boldsymbol{R_t}/\boldsymbol{R_{t0}}$ as function of magnetic field $\boldsymbol{H}$, which is received using known characteristics of ferrite ferromagnetic resonance [4], is shown on Fig.3, where $\boldsymbol{R_{t0}}$ - resonant transverse shunt impedance. The switching on the resonant magnetic field $\boldsymbol{H} = \boldsymbol{H_0}$ allows to decrease the transverse shunt impedance $\boldsymbol{R_t}$ more then 10 times. In according to (1) it provides with the essential increasing of maximum beam current $\boldsymbol{I_m}$.

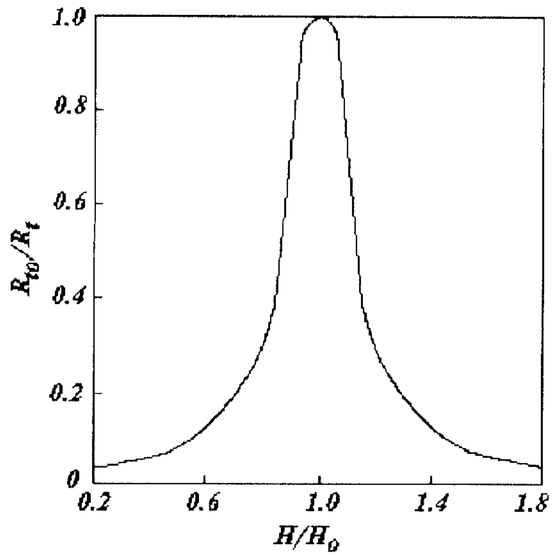

Figure 3. The dependence of transverse shunt impedance R_t as function of magnetic field H.

The parasitic E_{1n0}-modes have one field azimuth variation. The azimuth position of the polarization plane of the exited parasitic modes depends on the deviated beam azimuth position. Therefore, it is worth while to dispose two ferrite plates at 90° one after another in azimuth direction or more number of plates for a parasitic modes effective damping.

The using of the ferromagnetic resonance method is effective in induction accelerators, for example, ATA [2] or in storage energy low frequency accelerating resonators, for example, 4 MHz polycylindrical or polydisc resonators [1]. The one section of the induction accelerator with ferrite plates and windings of magnetic system is shown on Fig.4.

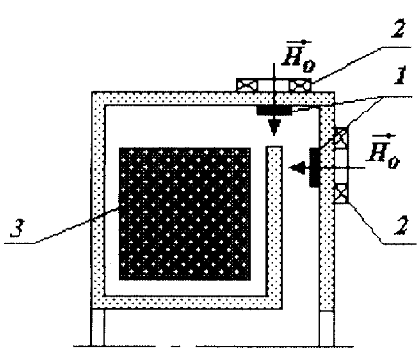

Figure 4. The using of ferromagnetic method in the induction accelerator. 1 - ferrite plate, 2- winding of magnetic system, 3 - core of inductor.

The RF-power loss in resonant accelerating structure on the operation mode frequency is increases at the putting the ferrite plates in the accelerating cavity, but decreasing of the operation mode longitudinal shunt impedance is essentially less then decreasing of the parasitic mode one.

The described ferromagnetic resonance method allows to damp several parasitic modes simultaneously. For this purpose it is necessary to fix several ferrite plates groups in the accelerating cavity. The each group is intended for the one parasitic mode damping. It is necessary to provide each plates group with constant magnetic field H_0 in accordance with (2) for one parasitic mode.

4. CONCLUSION

The considered methods of the struggle with pulse shortening effect may be effectively used both in the resonance LINACs and in the induction accelerators. For example, the ferrite plates are used in the induction accelerator ATA [3] in nonresonant regime, but the using of the ferromagnetic resonance method may allow to increase parasitic modes damping efficiency and to increase the beam current.

5. REFERENCES

[1] V.M.Anischuk, A.A.Zavadtsev, A.V.Mischenko, Yu.D.Petrov and V.M.Pirozhenko, "Radiofrequency Systems for Intensive Nanosecond Electron Beam Acceleration", Eighth International Conference on High-Power Particle Beams, Novosibirsk, July 2-5, 1990, p.220.

[2] B.T.Briggs, D.Z.Birx, G.T.Lapporaso, "Beam Dynamic in the ETA and ATA 10 kA Linear Induction Accelerator: Observation and Issues," IEEE Trans. on Nucl. Sci. Vol. NS-28, No.3, 1981, pp.3360-3364.

[3] E.L.Burstein and G.V.Voskresensky, "High Current Beams Linear Accelerators", Moscow: Atomizdat, 1970.

[4] O.S.Milovanov and N.P.Sobenin, "Radio-Frequency Technique", Moscow: Atomizdat, 1980, p.24.

[5] O.A.Valdner, G.G.Gurov, A.A.Zavadtsev, B.V.Zverev, V.V.Katalev, S.A.Kuznetsov, A.J.Malovitsky, E.S.Masunov, V.L.Morozov, N.P.Sobenin, I.I.Suligin, and B.K.Shembel, "Waveguide and Resonator Accelerating Systems for UNK," Serpuhov: IHEP 79-53, 1979, pp.25-38.