REGOTRON AS CW HIGH-POWER RF SOURCE FOR ION LINAC

I.V. Shumakov, B.P. Murin, B.I. Bondarev, A.P. Durkin
Moscow Radiotechnical Institute, Russia
113519, Russia, Moscow, Warshavskoe shosse, 132

Abstract

The problems and requirements to the RF power supply system are considered. Characteristic features of regotron-type generator are described. Physical processes that determine advantages of regotron in comparison with other RF generator with analogous beam parameters are considered. The problems of regotron operation into the accelerating structure are discussed.

The Problems And Requirements To The RF Power Supply Systems

The system of RF power supply of a high current linac is its most complex and expensive system which determines to a considerable degree the construction cost of the whole accelerating complex and its reliability. The required parameters of this system may be formulated only after studying of the linac design as a whole since some of them determine the linac structure. These are the output power of a generator, its efficiency, the term of faultless operation, the range of automatically controlled RF field amplitude and phase variation in accelerating cavities and so on. For the time being a multichannel RF power supply system with a power ramification at a low level is widespread. It is used, for example, in I-2 (ITEP) [1], MMF [2, 3] and LAMPF [4]. The two contradictory requirements gave rise to such a system: on the one hand, maintenance of accelerating fields in cavities requires a high level of RF power a certain portion of which is transferred to the beam, on the other hand, it is necessary to regulate RF voltage phase at the low power level (approximately 1 W). The last requirement is connected with the absence of powerful fast phase-shifter. Such a scheme allows to fulfill the longitudinal particles dynamics requirements: to provide amplitude stabilization accuracy to ± 0.1% and phase stabilization accurate to $\pm 0.5^0$.

The traditional scheme has RF supply channels quantity usually equal to the number of the accelerating cavities. Together with this the value of RF power, consumed by the accelerating cavity and the beam, is determined by the generator output power.

It is easy to notice that with the essential increase of the consumed by the accelerator RF power, the requirements must grow also, firstly, to the powerful output tubes of the generator. Naturally, the construction and reliability of the high-current linac will be possible when solving the problem of provision it with extra-reliable RF amplifiers of the increased power. Linac reliability increases with the increase of output power of RF channels (because of channels number decrease). So it is appropriate to use generator with output power of about 5 MW and efficiency up to 70%.

Regotron

As it was mentioned, it is necessary to have channel RF power amplifiers of P ~ 5 MW and efficiency of > 70% to provide RF supply system of continuous mode linac reliable operation with a total power of 500 MW. Nowadays this device is under development in MRTI by the name "regotron".

Firstly, the idea of such amplifier was suggested in the paper [5]. In the papers [6, 7] one can find the development of the idea before its realization by the scheme "regotron" [8]. By now regotron theory is worked out, mathematical simulation of the main processes programs are created and the first nature experiments are began.

The principle regotron scheme is shown in Fig. 1. Low perveance electron gun (1), klystron type buncher (2) and distributed RF power takeoff system (4) were used in it. The distributed power takeoff system consists of a number of (N + M) disconnected active (N) (see n.5) and passive (M) cavities (see n.6).

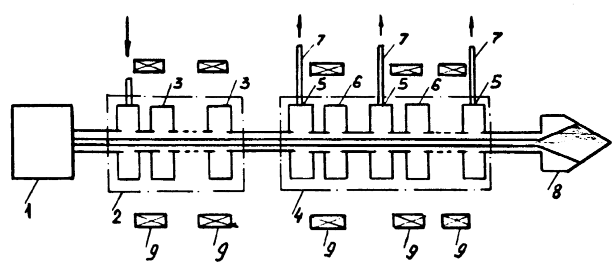

Fig. 1. Regotron scheme. 1 - high voltage electron gun; 2 - buncher; 3 - buncher passive cavities; 4 - distributed RF power takeoff system; 5 - active cavity; 6 - passive cavity; 7 - RF feeder; 8 - collector; 9 - focusing solenoid

When specifying maximum (limited) klystron power as P, maximum regotron power may be determined as following:

$$P_R = N \cdot P_{kl} = P_0 \cdot \eta$$

Where $P_0 = U \cdot I$ - electron beam power at the output of the electron gun, η - regotron efficiency. (Power limited value, usually determined by the electric rigidness of the dielectric window).

If beam losses are neglected in the device tract the efficiency may be determined by the equation

$$\eta = 1 - P_{col}/P_0$$

where P_{col} - beam power in the collector. In order to decrease P_{col} in the distributed takeoff system it is necessary to implement a well-known in the field of proton (ion) linac technology autophasing method, which allows to bring clustered electron bunches in the process of takeoff RF power by active cavities up to small energy values.

The autophasing effect is produced by couples of cavities [6] of which the active one with the resonant frequency equal to the signal frequency takes off RF power from the beam and the passive one detuned to an angle nearing π/2 bunches the beam without change of its average energy. The proper choice of parameters of both cavities determines the synchronous phase.

Theoretical calculations show that efficiency of 0.9 is achievable with voltage about 1 MV. But magnetic bunching must be applied to the beam of such a high energy, the realization of which gives rise to certain problems. The additional investigation shows that regotron is highly efficient with lower beam energy about 500 keV. In this case routine klystron bunching serves well and therefore the generator RF system consists of single toroidal cavities with drift tubes between them [15]. For focusing solenoid lenses on permanent magnets are preferable.

The beam dynamics investigation showed that phase oscillations amplitude is determined by the combination of parameters l/p^3R_n , where l is the distance between neighboring active cavities; p - the mean value of the beam reduced momentum in the n-th cavity, R_n - the n-th couple passive cavity shunt impedance. The proper choice of l, R_n depending on the deceleration rate, compensates considerably the parametric growth of phase oscillations amplitude. The 5 MW regotron efficiency is more than 70% at the frequency of 991 MHz.

The regotron main parameters are shown in Table 1.

It is necessary to mention that in spite of very high total power all the regotron elements may be made with necessary supply in the electric ruggedness and heating. This allows to maintain high reliability of regotron.

Table 1
The 991 MHz Regotron Parameters

Voltage	500 kV
Current	15 A
Excitation power	0.2...0.5 kW
Overall output power	5 MW
Power per an output	0.75 MW
Efficiency	> 70%
Buncher cavities number	3
Power takeoff system cavities number	15 (7 active)
Buncher length	5 m
Power takeoff system length	2.8 m
Overall length	7.8 m

Regotron Operation Into Accelerating Structure

It is appropriate to use biperiodic accelerating structure with disks and washers (D&W) for protons acceleration from 100 MeV to units GeV. This structure has been used at the main part of linear proton accelerator MMF. With the choice of this structure has been done on the base of close examination of radiotechnical, tuning, structural and technological parameters of side-coupled structure and D&W one. Because of very high coupling factor between cells (from 20% to 50%) D&W structure has a number of advantages in comparison with other biperiodic ones:

– vacuum conductivity is tens times larger;
– rather simple construction and manufacture technology;
– thither stability of accelerating field relative to manufacture errors, tuning errors and beam loading (accelerating field sensitivity to disturbances is inversely proportional to coupling factor squared).

The last advantage allows to simplify structure tuning and, consequently, to decrease cost of accelerating structure. Structure has high shunt impedance.

The number of cavity entry equals to the number of regotron outputs. It is appropriate to vary total regotron power during the tests and operation by regulating the current of electron gun. (In this case distribution of power along regotron outputs is more uniform). For fine-tuning of operating mode frequency and coupling oscillation it is necessary to vary geometry of module for power entry. Characteristics of the D&W structure (high coupling factor) allows to achieve demanded distribution of accelerating field.

Conclusion

The previous analysis has shown that regotron is the only RF amplifier which can meet the requirements for the main (high energy) linac part. In this case RF power supply system will consist of 50–70 channels of amplification and coefficient of linac downtime because of supply system failure will approximately the same value as for LAMPF. In the case of 1 MW klystron use, RF channel number have to be increase in 5–7 times. Downtime coefficient increase respectively and it may amount to 15–30%. At the first linac part RF system has to provide power of the order of 20–30 MW. Taking into account moderate power in this accelerator part, both klystrons and regotrons can be use. However in this case regotron use is preferable, because of the high reliability of the system operation. Regotron help to solve problems of design of CW linacs with current of 100–300 mA for accelerator transmutation [9–11].

References

[1] V.A. Batalin, E.N. Danil'tsev, A.A. Zhdanko, I.M. Kapchinskiy, V.G. Kul'man, N.V. Lazarev, B.P. Murin, I.Kh. Nevjazhskiy, V.K. Plotnikov, B.I. Poljakov, N.K. Titov, Proton Linear Accelerator I-2 on the Energy of 25 MeV, - In: PTI, 1967, No. 5, p. 9-12.
[2] B.P. Murin, A.P. Fedotov, V.G. Kulman, G.I. Batskikh, B.I. Polyakov, High-Current Ion Linear Accelerator for Medium-Energy Physics, *Proc. of the 1972 Proton Linear Accelerator Conference*. USA, Los-Alamos, LASL, 1972, p. 387–395.
[3] Accelerator Complex for Mean Energy Physics (Meson Facility), Proc. of Radiotechnical Institute, No. 16, Moscow, 1974.
[4] D.C. Hagerman, LAMPF Operation at 500 A, *Proc. of the 1979 Linear Accelerator Conference.* USA, Brookhaven National Laboratory, 1979, p. 78–82.
[5] F.A. Vodopjanov, B.P. Murin, RF Generator Method Based on the Used of Relaitvistic Electron Beam, - In: Collected Volume

"Accelerator Technology", - Moscow, RTI Ac. Sci., 1975, pp. 20–23.

[6] B.P. Murin, L.G. Lomize, A.E. Sominskiy, Deceleration of Relativistic Electron Bunches in Stretched Cavity System. In: Relativistic Microwave Generators, Theory and Technology, Moscow, RTI Ac. Sci., 1988, pp. 96–100.

[7] B.P. Murin, A.P. Durkin, O.Yu. Shlygin, Electron Beam Bunching in a Microwave Quasicontinuous-Mode Generator, - In: Relativistic Microwave Generators. Theory and Technology, Moscow, RTI, Ac. Sci., 1988, pp. 76–84.

[8] B.P. Murin, A.P. Durkin, O.Yu. Shligin, I.V. Shumakov, Super-Power RF Regotron-Type Generator for Linear Accelerator with High Mean Currents. *Proceedings of the 1990 Linear Accelerator Conference*. Albuquerque, New Mexico, pp. 584–586.

[9] G. Batskikh et al., Linear Accelerator for burner-reactor. *Proceedings of 1990 Linear Accelerator Conference,* Albuquerque, New Mexico, pp. 581–583.

[10] B.P. Murin. The Prospects For High-Power Ion Linear Accelerator Construction For Energy Function. Preprint 9210, Moscow Radiotechnical Institute, 1992.

[11] B.P. Murin et al., The New Concepts in Designing the CW High-Current Linacs, *Proceedings of the 1995 Particl Accelerator Conference,* Volume 2, pp. 1134–1136.

[12] B.P. Murin et al., Ion Linacs Design with Superconductivity Use. *This Conference.*