

# SMALL-SIZED ELECTRON LINEAR RF ACCELERATOR WITH BEAM AUTOACCELERATION FOR GEOLOGY AND INDUSTRY

B.Yu.Bogdanovich, V.I.Kaminsky, V.A.Senyukov and A.V.Nesterovich,  
Moscow State Physical-Engineering Institute (Technical University), Moscow, Russia.

## Abstract

The paper deals with the project of a small-sized electron linear RF accelerator with a beam energy up to 1 MeV, intended for use in bore holes for geological purposes. The application of autoacceleration method allows to exclude a high-frequency generator and therefore essentially reduce the installation dimensions. A single electron beam generates RF power at the initial part of the accelerating structure, and at other — longer — part this RF power is used for acceleration of a small part of this beam. For RF-power generated at 3.5 - 4.5 GHz frequency band the accelerating structure diameter (for iris-loaded waveguide) can be about 70-90 mm or less. A high voltage pulses (10-20 kV) are required for this accelerator operation. This pulses can be supplied with the help of cable, the length of which can be reasonably large. Such accelerator can be used for other purposes, as well, where the special requirements to a system dimensions occurs, and may be designed for exploitation in mobile (on a automobile) or portable variants.

The main purpose of the electron linac suggested in this paper is using for geological prospecting in bore holes. However such accelerator can find wide application for other purposes, where small dimensions of unit are required. The necessity of the accelerator work inside a bore holes imposes the specific requirements for its parameters and, first of all, on its overall dimensions. The accelerator's diameter, including all its auxiliary systems, should not exceed 70-80 mm at whole length up to 2 m. The accelerator should create an electron beam with energy about 0.5-1 MeV at average current  $\sim 1 \mu\text{A}$ . Any special requirements to power spectrum of a beam or its sizes are not declared. The accelerator from an external source can be feed by direct or pulse voltage up to 20 kV. Therefore it is desirable, that all systems of the accelerator should use voltages not higher than this one.

Now in geological prospecting for research of chisel chinks the direct action accelerators with voltage up to 500 kV are applied. The usage of higher voltage in specified dimensions is practically impossible. More over, such voltages can be received only during very short pulses (up to 100 ns). Such duration of pulses appear to be not enough for normal work of the measuring equipment. The more acceptable parameters of an accelerated beam can be received using linear resonant electron accelerator. A main problem at such accelerator design is creation a proper accelerating structure and forming an accelerating RF wave with necessary power.

The problem is that there are no any serial sources of RF power (generators or amplifiers) with output pulse power levels about 100-150 kW and appropriate dimensions. On the other hand, the RF power source cannot be dislocated on surface, also. At large depths of immersing (some hundreds meters) the real attenuation of RF power in any transfer line will be so large, that a source with output power on some orders more, than it is necessary for acceleration, is required. Hence, the construction of the electron resonant accelerator under standard circuit with an external RF source is rather inconvenient.

One of possible ways of this problem decision is a creation of the accelerator with an electron beam autoacceleration [1]. It's expediently to use autoacceleration of previously bunched beam for increasing such accelerator general efficiency. Actually in such accelerator the functions of particle injector and RF source are combined. The general configuration of such accelerator is shown on fig.1.

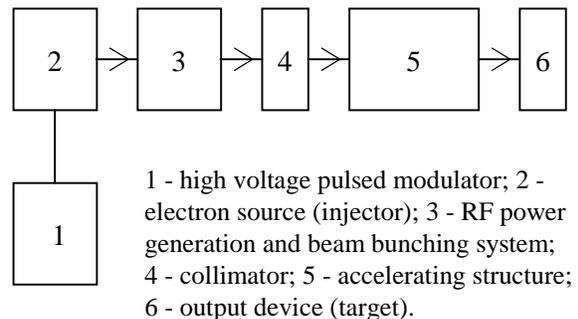


Fig.1. The general configuration of the electron accelerator with bunched beam autoacceleration.

The choice of accelerating structure type and working frequency band of accelerating wave is of great importance for limited transverse sizes accelerator design. As a separate RF source (generator or amplifier) usage in designed accelerator is not supposed, the appropriate RF frequency band choice is not limited by the nomenclature of industrial fabricated RF devices. Therefore operating frequency band can be chosen from following reasons. On the one hand, with reduction of RF frequency a power losses in RF elements (in particular, in accelerating structure) decrease. Besides the requirements for accelerating structure manufacturing and setup admissions are reduced for such frequencies also. It may be important for the accelerator cost reduction and for expansion of the

accelerator possible use areas. In this case it can be applied in wider temperature range (that represents the special interest for work in chinks on large depths), and in adverse mechanical influence conditions (vibration, impacts) also. On the other hand, an accelerating field frequency increase permits to reduce the transverse sizes of accelerating structure and, hence, to apply more simple and cheap structure types, for example, iris loaded waveguide (ILW). Thus, the choice of an accelerating structure particular type is a compromise between two requirements mentioned.

Accelerating structures of both types (with running or standing waves) can be used here. As accelerating structure with running waves the ILW can be applied. The accelerating structure external diameter may be about 70-80 mm for accelerating field frequency band 3.5-4.5 GHz. Real values of such structure shunt impedance are at range of 35-40 MΩ/m at attenuation factor about 0.1 m<sup>-1</sup>. Such section application will allow to receive an accelerated electron beam with energy ~1 MeV at length 1 m and RF wave power 140 kW (as the accelerated current value is rather small, one can neglect the current loading effects). The accelerating structures with standing waves are seemed to be more effective. As a standing wave structure the hyperperiodic accelerating structures (BAS) can be used. The transverse sizes of such structures can be the same, as of the ILW, but they can provide much higher values of shunt impedance, the real values of which are about 60-70 MΩ/m. The equivalent accelerating voltage in such structure  $U$  can be estimated by the following expression [2]:

$$U = \sqrt{\frac{2\alpha R_{sh} P_o}{1 - e^{-4\alpha L}}} \cdot \frac{1 - e^{-\alpha L}}{\alpha} \quad (1)$$

where  $\alpha$  - attenuation in accelerating section;  $R_{sh}$  - the section shunt impedance;  $P_o$  - RF wave power at the accelerating section entrance;  $L$  - accelerating section length.

The diagrams of accelerating voltage  $U$  dependence on the accelerating section length  $L$  for some values of RF wave input power  $P_o$  are shown at fig.2.

According to diagrams given the necessary values of accelerating wave power and the section lengths for BAS type standing waves structures are appreciably lower, than that for the running waves structures. So, for structures 0.5-0.6 m long the necessary values of input power is of order of 50-60 kW for 1 MeV beam energy. And a 0.5 MeV beam can be received at RF power about 15-17 kW. It permits to appreciably simplify an initial — generator and beam bunching — part of the accelerator. It is important to note, that in general case the BAS type structure cost is larger than ILW one. However, for this accelerator, where during the entire acceleration process electron beam is not strongly relativistic, the BAS and ILW costs, obviously, will not differ essentially, since

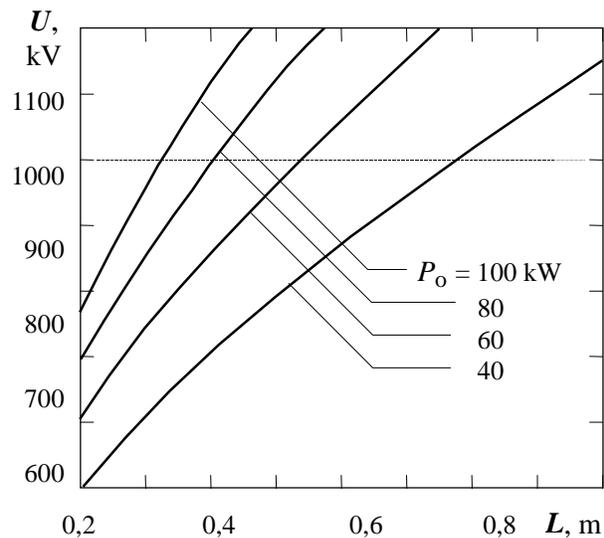


Fig.2. The equivalent accelerating voltage  $U$  dependence on the accelerating section length  $L$  for some values of RF wave input power  $P_o$  ( $\alpha = 0.1 \text{ m}^{-1}$ ;  $R_{sh} = 60 \text{ M}\Omega/\text{m}$ ).

application of structures with variable parameters through out a section are necessary in both cases.

Other important part of such accelerator is a primer part, where the RF power generation and beam bunching processes are taking places. The most simple and cheap, but at the same time rather effective, way of RF power generation with simultaneous beam bunching is usage of a klystron type device. The device efficiency, that can be really achieved, is about 30-35%. This is quite acceptable. So necessary initial electron beam pulse power should be at the range from 50 to 200 kW (with duty factor about 0.001). For anode voltage of 20 kV beam current should be within 2.5-10 A. This values are perfectly real. For the system dimensions reduction the beam focusing system energy consumption decrease the beam focusing field can be formed by constant magnets, located between transient resonators. Though in some cases focusing coils can be used as well. For large beam currents (up to 10 A) a multibeam system can be used. In this case a number of beams (7-10) with currents of 0.8-1.0 A each are used instead of single one. It does not practically require any changing of focusing system, but permits to increase beam with resonators interaction efficiency. The account of this accelerator part can be made on standard methods for klystron amplifiers [3]. As the electron energy in generating part of the accelerator is rather small, an effective enough particles bunching can be received for this part 30-40 cm long and one or two transient resonators. A feedback line connecting the output and bunching resonators is used for creation an auto generation conditions in this klystron system. For example, this line can be the coaxial type, as operating power levels are about tens-hundreds watts for klystron system amplification of the order 30 dB. A processed

electron beam from the output resonator passes through the collimator, which also plays a role of a collector, as absorbs a larger part of electron beam. For this reason it must be bulky enough and requires a coercive cooling (internal or external). Also the bulky collector reduces the bremsstrahlung formed by electron beam, which in number of cases can cause some difficulties in accelerating structure operation [4].

An additional advantage of such system is that a traditional element of accelerating structures - a wave type transformer is excluded. In common case such device is necessary because the RF wave types in feeding waveguides and accelerating section are different. Here the output resonator of RF source and accelerating structure operates with the same wave type that is  $E_{01}$ . Into accelerating section RF wave is transferred through coupling aperture (or apertures) connecting the generator output resonator and the first cell of accelerating structure.

As it was already mentioned, the accelerated current should be not higher than 1-10 mA. This value is rather small from the points of view of current loading effects and beam focusing requirements either. Therefore it is not supposed to use any special focusing devices in accelerating structure.

One more important question deals with accelerator inside volume vacuum pumping. Because of accelerator sizes limitation its practically impossible to perform a necessary vacuum pumping using traditional systems. A completely enclosed system with getter pumping like those used in small power electronic devices or system with small-sized pumps with discharge in magnetic field usually applied in powerful electronic devices (with possibility of external initial vacuum pumping) can be used here. The first variant is cheaper and at small initial electron beam power will possess an operation during several hundreds of hours. In many cases its quite enough for bore holes research, but assumes rather low cost of all installation. The second variant seems to be more real. Here during the accelerator work vacuum pumping is carried out with the help of internal pump, and after certain operation period the initial vacuum (if needed) and the high vacuum pumping are carried out by external

vacuum units. Thus restoration of the internal pump is possible. Such system is a little bit more complex, but permits more effective accelerator usage, especially, if its cost appears to be high enough.

Thus, according the analysis been made the general scheme of the accelerator can be presented as following (see fig.3). The accelerator consists of the following main elements: the electron source (electron injector) with pulse current within 2.5-10 A (single- or multibeam), the bunching resonator, drift channel with a number of transient resonators and a beam focusing system, the output resonator, a feedback line between the bunching (input) and output resonators, the collimator with coupling apertures, the accelerating structure (probably a BAS type) and the output device (target). General length of such accelerator will be about 1 meter at gross weight ~20-25 kg, certainly, with external power supply unit dimensions and weight not taking into account. On tentative estimations the cost of such accelerator can be about k\$100.0-150.0 for single unit and about k\$50.0-100.0 or less if fabricating in series.

### REFERENCES

- [1] B.Yu.Bogdanovich, N.M.Gavrilov and A.V.Shalnov. 'Uskoritely s nakopleniem i generatsiey vysokochastotnoy energiy', Moskva, Energoatomizdat, 1991 (in russian).
- [2] A.N.Lebedev and A.V.Shalnov. 'Osnovy fiziky i tekhniki uskoriteley', Moskva, Energoatomizdat, 1991 (in russian).
- [3] A.N.Lebedev. 'Tekhnika i pribory SVCh', Vol.2, Moskva, Vyshaya Shkola, 1970 (in russian).
- [4] B.Yu. Bogdanovich, V.A. Nesterovich and M.A. Tubaev. 'Vliyanye plazmy VCh rasryada na elektrodinamicheskiye charakteristiki uskoryayushchey struktur LUE i vychodnye parametry puchka', Preprint MEPhI 002-93, M., MEPhI, 1993.

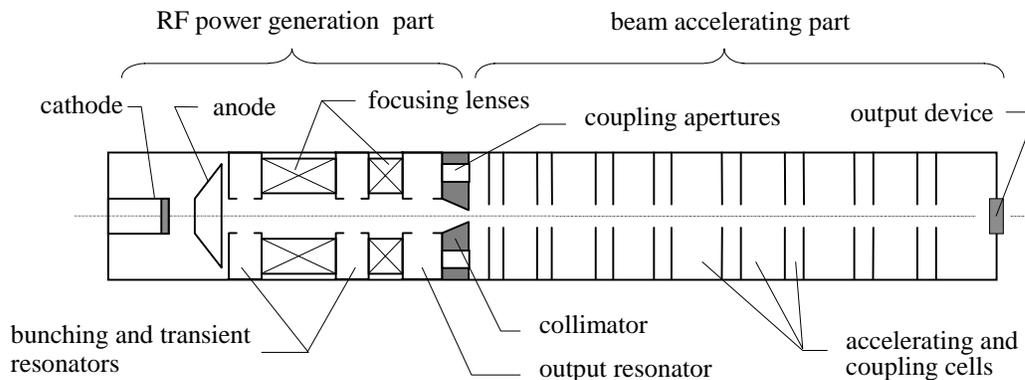


Fig.3. The general scheme of the electron accelerator with bunched beam auto acceleration.