POSSIBILITIES OF LU-50 LINEAR ELECTRON ACCELERATOR MODIFICATION

N.V. Zavyalov, A.V. Telnov, Yu.A. Khokhlov, I.V. Shorikov
Russian Federal Nuclear Center – All-Russia Scientific Research Institute of Experimental Physics, Sarov, Russian Federation

INTRODUCTION

The most significant trends of accelerator development are efficiency increase and widening of the designed installation functional possibilities. LU-50 accelerator was designed in the late seventies when there existed an acute necessity in measuring nuclear constants; for this purpose it was needed to generate short electron pulses (10ns) with maximum permissible current (up to 10A) to insure the technique of time-of-flight neutron spectroscopy [1]. On LU-50 there was obtained a $2\cdot10^{13}$neutr/s fluence of neutrons at the electron beam average power of 10kW. Now there arise new physics tasks requiring high values of the beam average current, they are: investigation of a process of neutrons multiplication in media for the purpose of creating a sub-critical frequency two-cascade power blanket [2]; neutronography of materials at the investigation of phase transitions in solid states on the basis of neutron wave properties at the energies of ≈ 0.01eV; radiation resistance investigations. Thus, it was proposed to perfect LU-50 accelerator [3] for their effective solution.

The most characteristic accelerators for neutron researches are as follows: GELINA (150MeV, IRMM, Geel), ORELA (140MeV, ORNL, Oak Ridge), CLIO (50MeV, LURE, Orsay) [3] and a new 100MeV accelerator (PAL, Korea) [4]. All these installations except for ORELA (1969) operate both in the mode of stored energy and on a long pulse; as injector there are used grouping sections, and AS with a long-time filling by microwave power (more than 1μs) are applied.

1. ANALYSIS OF LU-50 ELECTRON DYNAMICS

To determine possible ways of the accelerator perfection and to reveal the reasons of LU-50 beam current losses there were performed numeric calculations of electron dynamics in the mode of stored energy. It assisted in testing the program of calculation and made it possible to compare the results with the calculations performed in MEPhI [5,6]. The operation of LU-50 accelerating structure is based on the principle of using microwave energy stored in a circular iris waveguide (CIW). The accelerating guide consists of two similar accelerating sections (AS) with varied geometry and long time of filling with microwave power (≈0.94μs). AS operates on the wavelength of 16,5cm with 2π/3 oscillation type. A 50-kV diode gun with a cylindrical resonator excited on E_{010} wave is used as an injector. A microwave generator consists of MI-328 magnetron (exciter) and MIU-34 magnetron with 30MW pulse power and 100kW average power. The output power of the amplifying magnetron is divided into two similar channels (arms). The first arm of microwave generator feeds the first AS, some share of power (about 10%) is fed through a directed coupler and phase-shifter to a grouping resonator. The second arm is connected to the second AS through a waveguide phase shifter of trombone type.

In the calculation program there is applied an algorithm of one-particle approximation at which each particle corresponds to the charge injected over the time of microwave phase change by 10°. To describe the formation of one bunch (360°) there were used in the calculation 35 particles uniformly distributed over the whole period of accelerating field and discretely describing phase motion of continuously injected electrons. The calculations were performed for 21 electron bunches what corresponds to 11.5ns pulse duration.

It follows from the calculations that one can get a well-grouped bunch of 25% of the particles injected. Its nucleus will be as long as 15°, i.e. 22.9ps. The process of bunches grouping is completed at the beginning of the first section, during the second section there only takes place the acceleration.

The analysis of the results of numeric simulation of LU-50 electrons dynamics demonstrated that basic current losses fall on the initial stage of acceleration – resonator (50%) and on the output to the first section (25%). The resonator in which any slight deviation in the field strength leads to the deviation from the optimum phase of bunches flight into AS turned out to be of particular criticality for the sustain of the operation mode. As a whole, the calculation parameters coincided well with the experimental data and with the calculations performed before in MEPI. This points out to a sufficiently high degree of the chosen calculation model approximation to reality. The bunches duration experimentally determined through Cherenkov radiation registration in air constitutes 27ps [7], what corresponds to the phase duration of ~18°.

2. INVESTIGATION OF LU-50 PERFECTION POSSIBILITY

The researches on initiation of nuclear power two-cascade blanket and radiation resistance of materials formed premises for the LU-50 transfer to a more economically efficient operation mode with high average beam power.

There were performed before the numeric calculations of the versions of bunches grouping optimization for the purpose of increasing the LU-50 current pulse up to 20 A at 10ns duration. They demonstrated that such possibility does exist /5, 6/ and can be realized with no replacement of the available AS through:

- the addition of buncher with the supply power up to 15MW and constant loading factor equal to 0.1154.

- the introduction of additional accelerating resonator (klystron grouping) with pulse power not less than 100kW. This method is elaborated in theory and design.

The increase of LU-50 beam power can be also achieved by its transfer to the mode of the long-pulse current of accelerated electrons. The principle of using microwave energy stored in CIW when the current pulse duration (10ns) is by far shorter than the duration of microwave pulse (1.5μs) and filling time, is efficient only in the case of accelerating short pulses of high charge. In modern accelerators aimed at neutron researches the work requiring high average beam power is carried out in a more economically efficient mode of long current pulse (>1μs) acceleration when the power carried away by a microwave beam has time to be compensated by the generator.

At the analysis of initiated by the beam non-symmetric waves that are the reason of occurring the effect called “pulse break” there were obtained for AS of LU-50 the limitation by current of ~1,4A at the increased duration of the pulse up to 1μs [8]. The limitation by pulse that was found from the data of report [6] is of the same order.

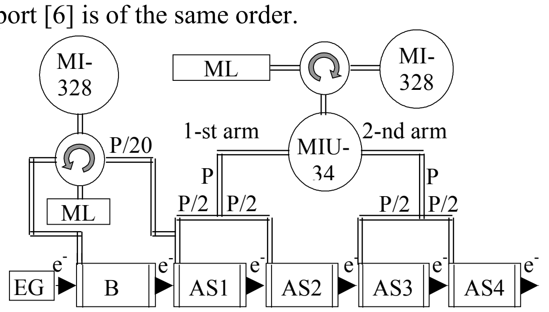

Fig.1. Structural scheme of the third version of modification: ML – matched load, EG – electron gun, B - buncher, AS – accelerating section.

From this it follows that there exists the possibility of increasing the average beam power by a factor of 2 both through the improvement of electron bunches grouping and through the transfer to the mode of current long pulse acceleration with no change in the accelerating structure. The more than double growth of the beam average power can be achieved through modification of the accelerating structure and (or) microwave supply. The scheme of a microwave generator used nowadays demonstrated its reliability under the condition of twenty-four-hour work. Thus, it is supposed that its basic assemblies will remain unchanged, the existing MIU-34 magnetron being taken as a basis.

In a new accelerating structure it is supposed to use a traveling wave buncher with 2π/3 mode to eliminate disadvantages caused by one-resonator grouping. In the first version considered a half of the first magnetron arm power was separated out for it. Then, at the left half release to the second traveling wave 2π/3-mode section one would manage to unify AS. For this purpose the second arm power can be split into two equal parts to feed the third and the fourth sections fully identical to the second one. The AS shortening assists in weakening the effect of “pulse break”, thus, there is considered the creation of a large number of waveguides but of shorter length (~2m).

Basic disadvantages of the first method consist in the increased supply power released to the buncher. This affects negatively to the phase grouping of bunches and to the capture coefficient at the acceleration mode. In this version one can succeed in implementing the capture of only 40% of particles at 15° phase extent of bunches.

Thus, there was considered the second version characterized by reduced microwave power fed to the buncher input. While considering different power splitting relations of the first magnetron arm there was found the most suitable proportion to meet the following criteria:

- minimum difference in power level;
- satisfactory phase grouping of particles;
- good phase capture to acceleration;
- equal filling time of bunching and accelerating sections.

At microwave supply of the buncher with 5MW (9MW for the second section) power, the above-mentioned criteria were satisfied best of all.

In the second version there were obtained at the accelerator output well-grouped bunches with the basic part phase extent not less than 8° at comparatively low scattering by energy of the order of 2MeV (4%). The disadvantages of this version consist in differences of AS by length and cell size and the differences of the corresponding guide components aimed at releasing microwave power. This will make it more difficult to produce and adjust the accelerator. Among the advantages of this method one can separate a good coefficient of phase capture to acceleration and grouping of electrons into bunches of short extent.

In the third version there were combined design advantages of the first two versions and the MI-328 magnetron-based microwave generator was added (fig.1). It is required to separate by power the bunching part of the accelerator from the accelerating one.

This will make it possible to flexibly implement the tuning to optimum beam parameters and to fully unify the production of AS. The power of each MIU-34 accelerating magnetron arm will be separated into two equal shares. It will be released to four absolutely identical sections whose aim is to accelerate the grouped bunches. Phase motion of bunches in these sections does not practically exist, thus, having once established the sections one must not reconstruct them even at microwave supply power change. Having separated by power the accelerating part one can adjust the buncher more accurately.

The main difficulty in realizing the third version consists, in comparison with the previous ones, in the system of microwave feeding with two generator magnetrons synchronization. Possible methods of magnetrons synchronization were described in several papers [9-11], through whose analysis there was chosen the system proposed.

In version 3 the buncher is fed from the MI-328 magnetron-based generator with the pulse power up to 6MW, while its synchronization is insured through the mechanism of pulling the frequency along with magnetron coupling through a circulator. MIU-34 will be a master oscillator, its main function consists in providing four AS with power (by 7 MW). The second magnetron MI-328 will serve as a modulator as it does now.

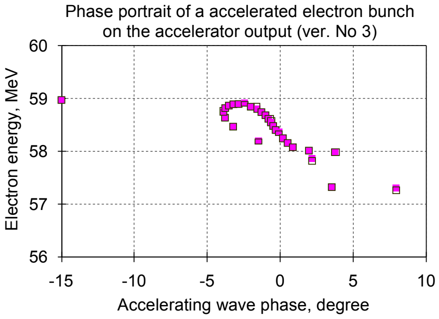

Fig. 2.

In this version electron bunches can be accelerated up to the energy of 58.3MeV, the scattering of the basic part of a bunch will constitute at 8° phase extent 1MeV (Fig.2). The calculation time of AS filling is equal to 0,67μs. The average beam power at operating in the long-pulse (2.5μs) mode is equal to 60.9kW.

3. CONCLUSION

A high-current accelerator applied to achieve in the first cascade a neutron flux of the order of 10^{14}–10^{15} per pulse is supposed to be used in the development of experiments in simulating two-cascade nuclear power boosters with unilateral coupling.

There exists the possibility of increasing the average beam power of LU-50 several times through a more efficient use of microwave energy. In the report there are analyzed different trends of LU-50 modification basing on the available microwave generator whose assemblies are well elaborated over a long period of its operation. It is shown that to increase the average beam power several times it is required to modify the LU-50 accelerating system as a whole. Among the modification versions most promising is the one that is more complex by the microwave feeding system consisting of a grouping section and four similar accelerating sections. This version makes it possible to considerably increase beam energy and to unify AS.

At the application of different methods of suppressing lateral oscillation modes, such as shortened AS and radial cuts on diaphragms one can operate more efficiently both in the mode of stored energy and on a long current pulse with the average beam power higher than 50kW. Such beam power allows to achieve the required fluence of neutrons and to carry out physics investigations requiring high intensity of electron, bremsstrahlung or neutron radiation fluxes.

4. REFERENCES

1. G.P.Antropov et al. VANT, 1985,.2/3/.-p.3-5.
2. Clendenin J. et al. Compendium of Scientific Linacs.-CERN.-XVIII Intern. Linac Conference.- Geneva, 1996.
3. Kim G.N. et al. \Proposed Neutron Facility Using 100-MeV Electron Linac at Pohang Accelerator Laboratory. -Conf. Proc. Nuclear Data for Science and Technology.-Trieste.-1997.-P.556.
4. Zavyalov N.V., Kolesov V.F. and Yu.A.Khokhlov On the Possibility of Experimental Testing for the Conception of Cascade Electronuclear Facilities Using ^{237}Np\ II Intern. Workshop: Nuclear Fission and Fission-Product Spectroscopy, Seysins, France. – 1998.
5. Majorov Ju.K., Zavyalov N.V., Khokhlov Yu.A.et al.. Particle dynamics in LU-50 accelerator and determination of the possibility of increasing the intensity of accelerated beam // XI All-Union Workshop on Linear Accelerators of Charged Particles (Kharkov, June 6-8, 1989) – Abstracts, p. 43 (in Russian).
6. Zavyalov N.V.,Ivanin I.A., In′kov V.I., Sitnikov N.P. et al // PTE.-1990 .-№3 .-p. 56-58.
7. Burshteyn E.L., Voskrecenskiy G.V. Linear electron accelerators with intensive beams. Moscow, Atomizdat Publ., 1970 (in Russian).
8. Khlopov Yu.N. Basics of magnetron usage. Moscow, “Sovetskoe Radio” Publ., 1967 (in Russian).
9. Vikulov V.F., Vinogradov K.A., Milovanov O.S. // Accelerators. - Moscow, Atomizdat Publ., 1968, v. 10, p.181 (in Russian).
10. Thal H.L. and Lock R.G. Locking of magnetrons by an injected RF signal.-IEEE Trans.-1965.-Nov.-MTT-13.- #6.-P.836.