AN ELECTRON LINAC PRODUCING BEAM POWER UP TO 15 KW

V.I.Beloglasov, A.I.Zykov, E.S.Zlunitsyn, G.D.Kramskoi, G.L.Fursov, National Science Center, Kharkov Institute of Physics&Technology (KIPT)

1 INTRODUCTION

LU-10 single-section electron Linac was commissioned in 1987 [1]. Up to mid - 1993 it had operated on KIU-53 klystron, producing electron beam with output energy within the maximum power spectrum $E_{j\ max}$ ≅10 MeV and average current I_{av}≅500 µa at a rep rate N=150 1/ sec. A necessity arose in 1993 to increase beam energy and output power. However, by this time KIU-53 klystrons were no longer produced by industry with only KIU-12 klystrons being available for this purpose. Since KIU-12 has the pulsed power operation value P_{pul}≅(20÷18)MW at N≅(50÷100) 1/sec, respectively, then, it was necessary that N be raised up to 300 s^{-1} with increasing P_{pul} up to (24÷26)MW, the decision was taken to upgrade the rf-power input source for the LU-10 accelerating section and employ in the new LU-10M a scheme of adding up the rf-power output from both KIU-12 klystrons. The earlier studies [2] gave a reason to believe that such a set-up should provide for a reliable operation of the accelerator and required beam parameters at N=300 1/sec and the power input operation P_{pul}≅(12÷13)MW from each of the two KIU-12 klystrons. To our knowledge, in the scientific literature there were no references concerning rf-power add-up in electron linacs, and probably, information on such a system can be of use.

2 UPGRADING THE LINAC RF-SYSTEM

By the beginning of upgrading we had basic equipment for a new waveguide system with a circuit of rf-power add-up, as well as for a high-voltage (HV) feeder of klystron modulator N2, and the appropriate place in the same building with the mainline klystron modulator N1 of the LU-10 accelerator. Therefore reconstruction fulfiled without long delay at moderate production costs. July 1993 saw the start of preparations for the upgrading and fabrication of the missing equipment; in October LU-10 was halted to dismounting the original rf-feeder source, and in November it re-started beam operation in upgraded version. LU-10M has had more then 13000 beam time hours since.

3 LU-10M RADIATION COMPLEX

LU-10M provides for the following parameters of electron beam:

- E_{Imax} is adjusted within the limits (6÷17)MeV;
- I_{av}- (5÷1400) µA;
- Maximum beam average power $(P_i)_{av}^{max} \cong (E_{I_{max}} \cdot I_{av}) \cong 15 kW$
- Current pulse duration τ_i=3,5µsec;
- Frequency send of the beam is adjusted within the limits N=(25÷300) 1/sec;

The main operation mode: E_{Imax}=(12-13) MeV and I_{av}~1000 µA.

The full width energetical spectrum of the beam on the halfheight-so called “halfwidth” - lies in limits (3÷6)% and depends from the operation mode accelerator.

Since 1994 at the radiation complex based on LU-10M research with has been going on in basic and applied areas of radiation damage physics, radiation technologies and pharmaceuticals sterilization. The complex is situated in a dedicated spacious seem-subterranean bunker a dependable bio-protection of the radiation danger zone, being equipped with a suspended conveyer belt, a load/unload and storage from for various items for a mass-scale radiation processing, and devices for target irradiation by large doses with necessary cooling. The complex is controlled from the operator′s panel in a separate room; klystron and electron gun modulators are placed in shielded chambers. The electricity-forming network for he klystron modulator N1, the electron gun and the system of beam forming-parameter (electromagnetic lenses, correctors, solenoid, etc.) are power-feed from a stabilized voltage source (P~150 kW, ΔU/U ~1%).This taken together with optimization accelerating section parameters, allows for a sufficiently high long -lasting stability of beam parameters, with the 24-hour mean variations in beam energy and current not more ±1,5%. The accelerator is equipped with metrologically licenced devices [3] for energy spectrum measurements and monitoring of average and pulsed (I_{pul}) beam current.

The general technical layout of the radiation accelerator complex and its support systems is traditional to a considerable degree. Having this in mind, we will just dwell on the rf-system and its functioning.

4 RF-FEEDER SYSTEM

During the upgrading two versions of rf-power adding-up were tested. The first one included a 3 dB-directional coupler with the waveguide (90x45) mm^2. It is constructionally convenient and earlier was tested in the gus-filling mode (nitrogen, pressure 6 at, P_{pul}~20MW at N=100 1/sec). Yet, in this case the coupler schould work in the vacuum mode, when its electric strength proved insufficient: at P_{pul}~20 MW sparkings occurred at the sites of welds leading to damage of the vacuum which coursed rf-discharges in the areas of high electric fields. It was found that the sparkings were caused by technological defects made during fabrication and welding, these defects having not been detected during the gas-filling tests. As a result, we had to reject the coupler and look upon a more technologically feasible thing, a double-waveguide T-bridge. After a certain rf-training of the waveguide system and acceleration section in assembly we managed to secure a stable operation mode at N=300 1/sec and the summed P_{pul} up to 27 MW at the adder output. A further increasing of P_{pul} was not attempted on account of modulator and klystron operation limitations, though,apparently, electric strength of the waveguide system and acceleration section could have allowed it. A schematic layout of the double T-bridge rf-feeder is given in Fig-1, where EG - electron gun, AS - acceleration section, SC-scanning magnet chamber, M - target, T-double T-bridge, CC- rf-window; the other designations being made elsewhere throughout the text.

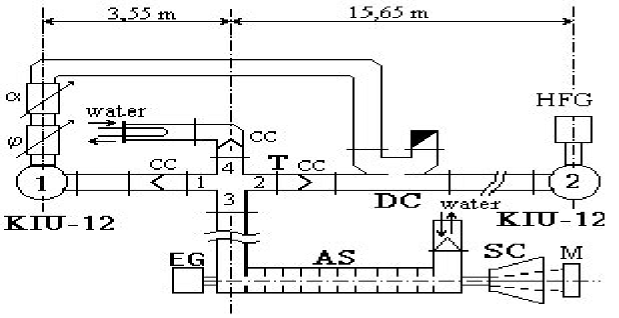

Fig.1
RF-Scheme LU-10M

Klystron N2 is excited by the re-driver generator HFG (f=2797,2 MHz, $\Delta f / f \sim 10^{-6}$on the day) acting itself as a driver for the klystron N1 through a by-pass waveguide line, using the directional coupler DC. The rf-signal phase and amplitude in shoulder 1 of the T-bridge is adjusted by the attenuator α and phase-shifter φ which serves for selection of the optimum signal phase difference in the shoulders 1 and 2. In order to decrease the signal phase temperature drift in the shoulder 1 the by-pass waveguide length is taken to be minimum, i.e. DC is placed immediately near the entrance parting of the shoulder 2. A change in the klystron 2 voltage regime does not change the working signal phase difference in the shoulders 1 and 2, i.e. the phase tuning is required only for voltage changes in the klystron 1. The klystron 2 rf-pulse is approximately 0.3μs longer then that of the klystron 1 which has been done for the convenience of phase-tuning on the power minimum in the shoulder 4. Signal phase-locking and control is performed with the aid of detector heads, positioned in the shoulders 3 and 4 (in Fig.1 the detectors are not shown). Power in the shoulders 3 and 4 is determined from the expressions:

$$\left.\begin{aligned} P_3 &= \frac{P_1 + P_2 + 2\sqrt{P_1 P_2}\cdot\cos\varphi}{2} \\ P_4 &= \frac{P_1 + P_2 - 2\sqrt{P_1 P_2}\cdot\cos\varphi}{2} \end{aligned}\right\} \qquad (1)$$

where P_1 and P_2 are power values, while φ is the signal phase difference in the shoulders 1 and 2.

If $\cos\varphi$=1 and P_1=P_2, then P_3=2P_1 and P_4=0, i.e., in the shoulder 3 there occurs a total power addition from the two klystrons. The addition coefficient

$$K_c = \frac{P_3}{P_1 + P_2}\cdot 100\% = \left(0{,}5 + \frac{\sqrt{P_1 P_2}}{P_1 + P_2}\right)\cdot 100\%$$

is sufficiently high even in such a case when P_1 and P_2 differ considerably in value. Thus, at P_1/P_2=2 K_c=97%.

5 AS LOAD CHARACTERISTIC

A circular slitted waveguide, similar to the one described in [4,5], serves as acceleration section, differing from the latter by a shortened length of the main part where the phase velocity of the fundamental mode E_{01} is equal to the speed of light (L_c=2,1 m). This is done in order to increase the efficiency of acceleration $I_{pul}>1A$; for this purpose, the waveguide disks have radial slots [6] to suppress HEM_{11}wave.

The calculated load characteristic AS determined in consideration of the power decay in it and in the feeder waveguide, and, considering the dynamics calculation data for longitudinal motion, has the form:

$$E_{I_{max}}(MeV) = 3{,}82\sqrt{P_3(MW)} - 5{,}75 I_{pul}(A) \quad (2)$$

It is shown in Fig.2 for the value P_3=23 MW. The dots indicate the measurements data.

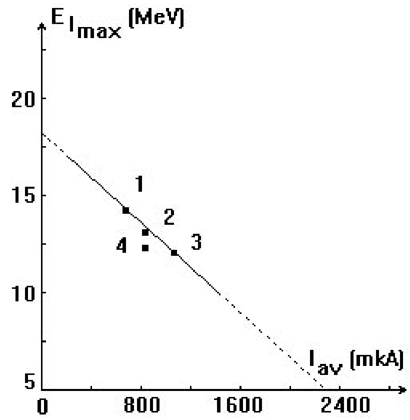

Fig.2
The Calculated Load Characterictic AS

Fig.3 shows the beam energy spectrum measures at I_{av}=900 µA and P_3=21,2 MW (dot 4 in Fig.2).

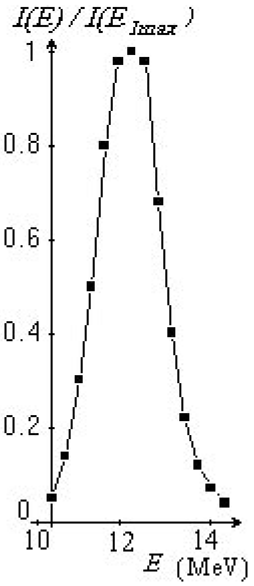

Fig.3
Energy Spectrum of the beam

6 FUNCTIONING

As shown above, during the rf-training a stable operation mode was achieved up to the value P_3=27 MW. This value at I_{av}=1000 µA corresponds to E_{Imax}=14,1MeV. However, in the main operation mode the level P_3 is lowered to 23 MW which produced E_{Imax}= 12,6 MeV at the current 1000 µA. This decrease is associated with the following:

- Requirement to de-limit the target and equipment activation in the radiation zone. At the full beam absorption with $(P_i)_{av}$~15 kW its radiation productivity is 1,5 MRad per second per 1 kg of the absorber; ~10% of power converted to γ-ray′s. At E_{Imax}>13 MeV there occurs a considerable increase of the intensity of threshold reactions (γ, *n*) and (γ, *p*)(in particular, owing to the high energy spectrum part′s), and accumulation of relatively long-lived radioactive nuclides which is undesirable at the conditions of a continious (around-the-clock) accelerator operation to mass-produce the irradiated products;
- Requirement to ensure a long lifetime klystron operation and HV-modulator equipment, considering that these facilities are in short supply and very costly. As a rule, even a slight decrease in their operation made wile gain considerable advantages in their operation service.

7 KIU-12 OPERATION SERVICE

During LU-10M operation service since 1994 up to now, all in all, 6 KIU-12 klystrons were used on it. One of them operated more then 11000 hours and was replaced on account of appr. 10% decrease af the power output; the second one (7500 workhours) was dismantled on account of the rf-window "lock-up", the third one (2100 hours) on account of a HV-insulator breakdown. The remaining three klystrons worked, on the overage, 800 hours and went out of operation for one and the some reason: vacuum loss due to a break in air-tight seals around the rf-input feeder which is a well-known technological defect characteristic of the production plant manufacturing KIU-12 klystrons. If one negleds the defect, then the average life of three KIU-12 klystrons was appr. 6800 h. If all six klystrons are taken together, then the average klystron life is appr. 3800 h.

8 REFERENCES

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