# High Power Sources for VLEPP

L.N. Arapov, P.V. Avrakhov, V.E. Balakin, V. Chashurin, S.Yu. Kazakov, N.G. Khavin, V.F. Kluev, G.S. Krynov, G.I. Kuznetsov, A.V. Larionov, A.N. Lukin, O.V. Pirogov, S.L. Samoilov, V.D. Shemelin, V.V. Shirokov, N.A. Solyak, V.E. Teryaev, Yu.D. Valyaev, V.F. Vogel, G.I. Yasnov

Budker INP, 630090, Novosibirsk,
Branch INP, 142284, Protvino,
Russia

*Abstract*

Design and experimental studies are now under way to create a relativistic klystron as possible RF power source for the linear collider VLEPP. The present status of this work is reported.

## 1 INTRODUCTION

The future of high energy physics is associated with linear colliders, construction of which is impossible without pulse RF sources of 100's $MW$ power range [1]. In the project of the VLEPP facility it is assumed to use as an RF source an amplifying relativistic klystron whose principal circuit and design calculations are presented in the report [2]. The design parameters of the klystron are given in Table 1.

Table 1: Klystron design parameters.

| | |
|---|---|
| Operating frequency | 14 $GHz$ |
| Beam energy | 1 $MV$ |
| Beam current | 300 $A$ |
| Pulse duration | 0.5 $\mu sec$ |
| Repetition rate | 150 $Hz$ |
| Peak output power | 150 $MW$ |
| Saturation gain | 80 $dB$ |
| Efficiency | 50% |

## 2 POWER SUPPLY SYSTEM

In contrast to most of projects where it is supposed to supply diode electron gun in a traditional way, with modulator using pulse transformer, in the VLEPP project klystron is supplied by constant voltage and current pulse is forming by pulse voltage on the grid electrode locating near cathode. There will be used one HV source for 20 klystrons of a 100-metres section of the accelerator. It leads to essential reducing of the project cost in comparison with traditional scheme requiring producing of thousands modulators with complicate, expensive and material consuming pulse transformers.

The drawing of the klystron together with HV source is shown in Fig.1.

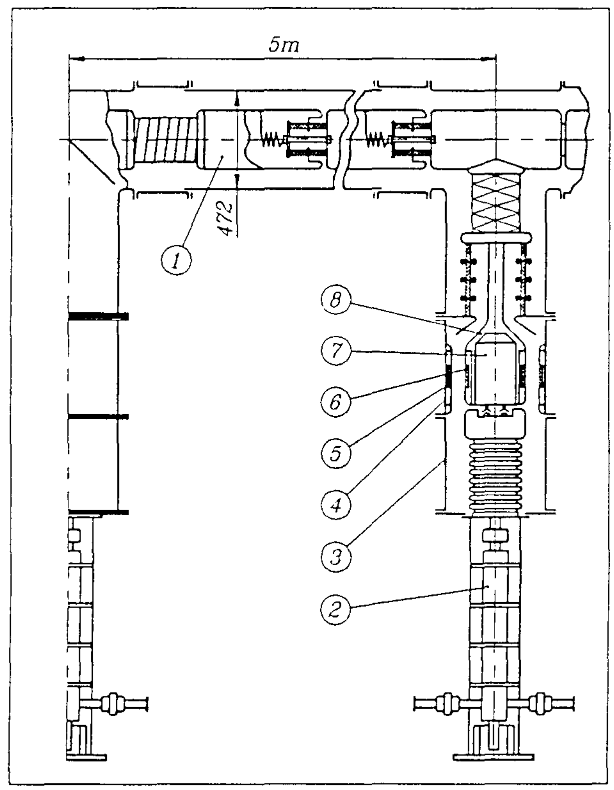


Figure 1: Klystron and forming line.

1. Forming line; 2. Klystron; 3. Klystron case; 4. Transformer case; 5. Primary coil of transformer; 6. Secondary coil of transformer; 7. Gun control unit; 8. HV input.

The basic element of the klystron HV source is coaxial forming line (FL) consisting of six identical cells. Wave resistance of the FL is 1200 $Ohm$, electrical length is 0.5 $\mu sec$. The volume is filled by $SF_6$ under pressure of 12 $atm$. The internal part of the FL is supported by insulators, below which the gun control unit (GCU) is placed. GCU provides power supply on the cathode unit and a pulse driving voltage on grid the electrode. Necessary for this purposes $1.5\,kW$ of power are inputting through the coaxial transformer with a gas gap, operating at frequency of $1\,kHz$. GCU is controlled using optic channel.

Voltage of $1\,MV$ on the acceleration tube of klystron is achieved, but at present measurements are carrying out typically at $0.7\,MV$.

## 3 ELECTRON GUN

To get electron beam current of $300\,A$ honeycomb oxide cathode with overall diameter $120\,mm$ and sphere radius of $100\,mm$ is used. The cathode consists of 37 cells, each of that is a separate microcathode with the sphere radius of $25\,mm$.

The grid electrode for beam control is thick enough – $6\,mm$ – in order to reduce the dark current. The electrode has holes which are coexistent with microcathodes so that each cell operates as separate gun with the Pierse's optics. After passing through the grid all microbeams joint to the whole macrobeam which is accelerated.

In the beginning while choosing the optics of acceleration tube the 2-D model was used in computer simulation. Four types of optic system were considered. The optimal current obtained from this simulations was of $200\div300\,A$ range. However, in the experiments this range was substantially lower, $130\div180\,A$. Because of such disagreement 3-D computer code for the multibeam gun simulation is developed (a typical picture produced by it is shown in Fig.2).

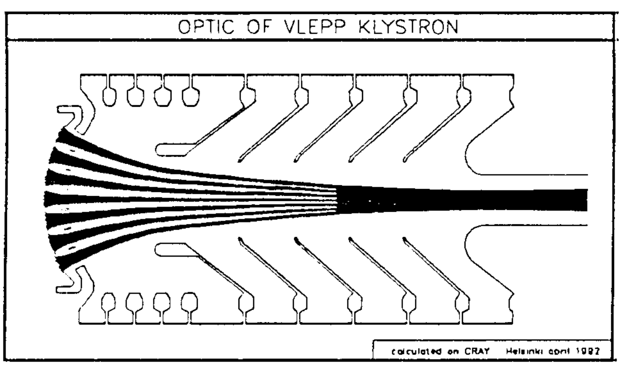


Figure 2: Optics of electron gun.

And later calculations give results which differ from experimental not more then on $5\div10\,\%$. The work for improvement of optics is to be continued.

## 4 RF GAIN SECTION

The next peculiarity of the klystron is an application of permanent magnets for the beam focusing beam in the RF gain section. This reduces total power consumption and leads to improvement of energy efficiency of the facility as a whole. Periodic focusing system has the acceptance of $0.05\pi$ so it is enough because the beam emmitance obtained from experiment is about $0.03\pi$. Main parameters of the magnetic periodical focusing system (MPFS) are presented in Table 2.

Table 2: Focusing system parameters.

| | |
|---|---|
| Aperture diameter | $11\,mm$ |
| Period of MPFS | $32\,mm$ |
| Number of periods | 20 |
| Field amplitude | $4\,kGs$ |
| Magnetic material | $Nd–Fe–B$ |
| Channel acceptance | $0.05\pi$ |

The results of computer simulation of the transverse beam dynamics in the RF gain section of the klystron at field of $4\,kGs$ are shown in Fig.3.

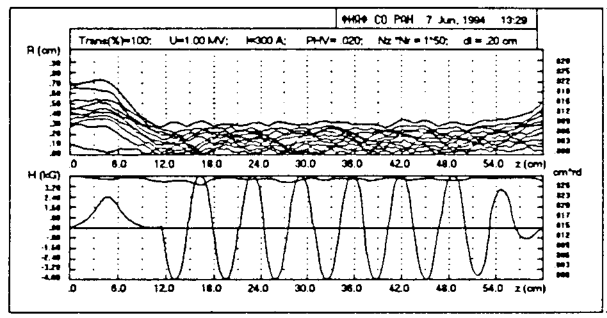


Figure 3: Transverse dynamics of the beam.

While computing beam space charge and angle spread of particles in the beam were taken into account. Isolines of the current are drawn with step of 10 %.

## 5 OUTPUT SYSTEM

An amplifying part of the klystron comprises an input and 7 passive resonators with resonant frequencies chosen in such a way as to provide the required gain in spite of low bunching efficiency of the relativistic beam. An output system of the klystron is made in the form of the iris loaded waveguide and a wave type transformer with two symmetrical waveguide power outputs. Main parameters of the output system are listed in Table 3.

Table 3: Output system parameters.

| | |
|---|---|
| Total length | $70\,mm$ |
| Aperture diameter | $16\,mm$ |
| Number of cells | 14 |
| Wave mode | $\pi/2$ |
| Phase velocity | $0.87\,c$ |
| Group velocity | $0.24\,c$ |
| Max surface field | $700\,kV/cm$ |

Traveling-wave structure of output system has two advantages in comparison with a single standing-wave cavity:

higher efficiency and lower surface electric fields.

Longitudinal dynamics of the beam was analyzed numerically with a model including interaction of the beam with travelling wave in output system. The results are presented in Fig.4.

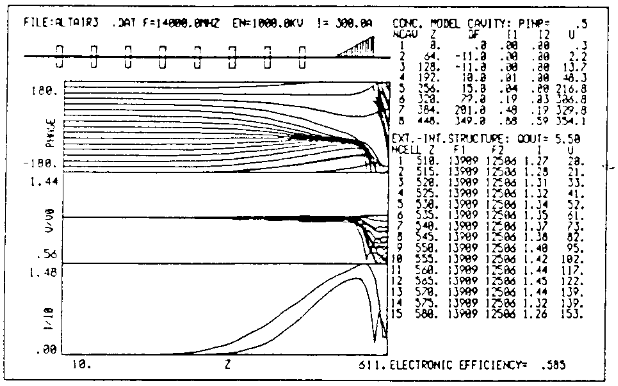

Figure 4: Longitudinal dynamics of the beam.

## 6 TEST RESULTS

At present, several versions of the device are tested. In Fig.5 summary diagram of cavities detunings for all versions of the klystron and corresponding gains are presented.

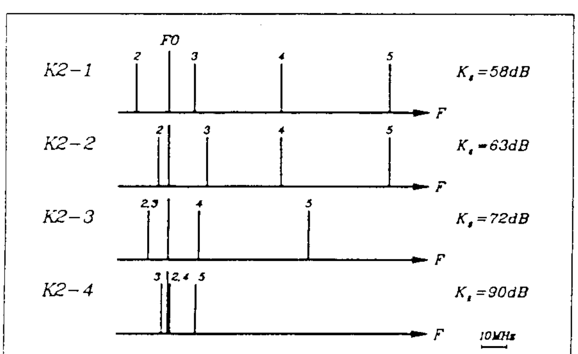


Figure 5: Diagram of cavity detunings for all versions of the klystron.

These experiments were carried out without output windows. At repetition rate of $1\,Hz$ and pulse duration of $0.7\,\mu sec$ a power about $50\,MW$ was obtained at the output of the device with a gain over $90\,dB$. Further increasing of the output power was restricted by klystron self-excitation. The current level in the collector of klystron, at which self-excitation occurred was in range of $140 \div 145\,A$.

In Fig.6 oscillograms of RF pulse envelopes for output power and collector current of the klystron are presented.

In Figs.7,8 the amplitude and amplitude-frequency characteristics of the present version are shown.

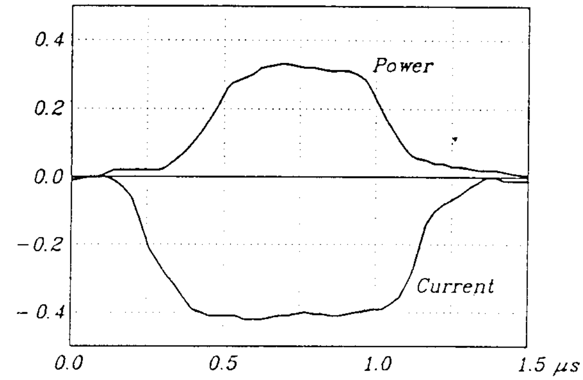


Figure 6: RF pulse envelopes for output power and collector current of the klystron.

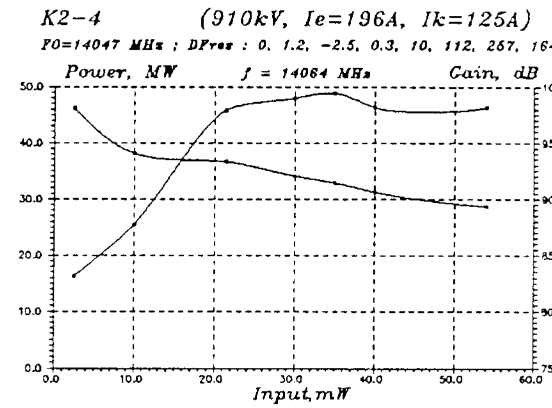


Figure 7: Amplitude characteristic of the klystron.

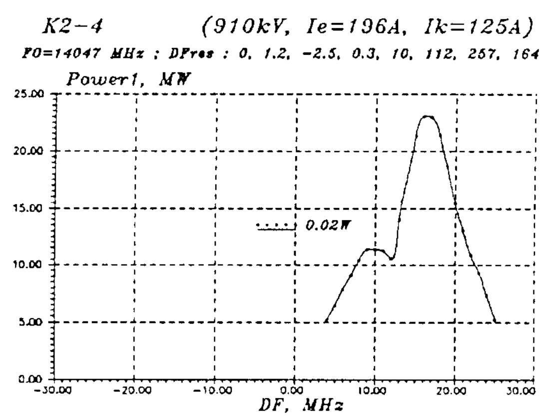


Figure 8: Amplitude-frequency characteristic of the klystron.

An energy extraction is intended to perform through two vacuum-tight windows made of ceramics BK-94-1. The RF-windows are of a "pill-box" construction with smooth tapers from the rectangular waveguide to the round one. To reduce electrical strength on the dielectric the window diameter was chosen three times more then the wave length. As it was tested experimentally such windows let pass power up to $10\,MW$ without breakdowns and distortions of the output pulse envelope. The measurements of losses in windows were carried out by a calorimetric method. The dependence of power in water cooling channels of both windows on the RF power is presented in Fig.9.

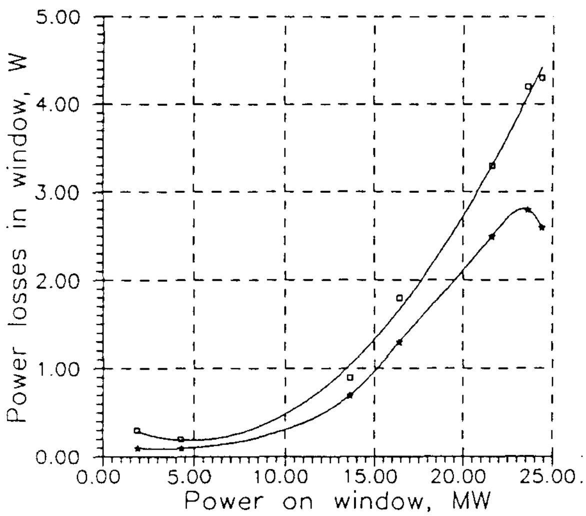


Figure 9: Power losses in the output window.

This plot shows nonlinear rise of losses, slightly differ for two windows, at RF power more than $10\,MW$. After disassembling, one could be see that the tracks of breakdowns had symmetrical, regular view, so it is possible to suppose that one of parasitic resonances was excites. The density of such resonances is high ($10\,MHz/resonance$) because the window diameter is big in comparison with the wave length. So probably it is difficult to avoid excitation of resonances located near to operation frequency. At present another type of window is under consideration.

## 7 SUMMARY

An analysis of the available experimental characteristics of the relativistic klystron has shown that for achieving the design parameters it is necessary to increase a beam current with the growth of which both the klystron output power and its gain increase. So far the current growth is limited by occurrence of parasitic oscillations that lead to the beam drop to the device walls and to the shortening the RF power pulse. Some certain contribution is also given by the presence of output windows having large losses, which, in its turn, causes the reflection from windows, deterioration of vacuum , and can also be resulted in the break-downs in the power extraction system.

## 8 REFERENCES


[1] *V.E. Balakin, G.I. Budker, A.N. Skrinsky,* "On possibility of creation of linear electron-positron colliders on superhigh energy." in Proc. of XI All-Union workshop on charge particle accelerators, Moscow, 1978. – p.27.

[2] *L.N. Arapov, V.E. Balakin, Yu.G. Bamburov et al.,* "The development of RF source." XII All-Union workshop on charge particle accelerators, Moscow, 1990. – p.173.