EXPERIMENTAL STUDY OF 100 MW WIDE-APERTURE X-BAND KLYSTRON WITH RF ABSORBING DRIFT TUBES

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Abstract

In this paper we present the results of experimental study of a wide aperture (15 mm), high gain (80 dB) VLEPP klystron upgraded with RF absorbing insertions. Investigations have been performed using the driving beam of the JINR LIA-3000 induction accelerator ($E = 1$ MeV, $I = 250$ A, $\tau = 250$ ns). The proposed technique for suppressing parasitic self-excitation proved to be extremely fruitful: we have obtained design output parameters of the klystron and achieved level of 100 MW output power.

1 INTRODUCTION

The cost of the RF system constitutes significant fraction of the total cost of the linear collider. To minimize the cost and to increase the efficiency and reliability of the RF system, all its elements (modulators, electrodynamic system of the klystron, focusing system of the klystron, low-power RF system of master amplifiers) can not be considered as independent pieces and one should perform overall optimization.

R&D work on relativistic klystron for VLEPP was started at the Budker Institute of Nuclear Physics more than ten years ago. It was accepted that focusing system of the klystron should be based on permanent magnets, because this reduces significantly operational cost with respect to electromagnetic solenoidal focusing [1]. The most cheapest modulator is considered in the VLEPP project which has appearance of distributed high-voltage power supply [2]. The control of the beam current is performed by means of gridded electron gun [1]. Providing the most cheapest design of the modulator, such an approach requires development of a large aperture klystron, because the electron beam quality of the gridded electron gun is worse than that of the simple diode gun. The problem of optimal choose of the power gain of the klystron can not be considered independently from the system of master low-power RF amplifiers. Semiconductor technology provides the possibility to construct low-cost, reliable and compact X-band amplifiers with output power of the order of 1 W. If the klystron will require a higher level of input power, the system of master amplifiers should be based on vacuum tube devices, which are less reliable and more complicated. Moreover, the problem of precise synchronization and phase stability becomes more severe at higher level of RF power. Taking into account that peak power of the klystron should be of the order of 100 MW, the power gain of 80 dB has been chosen as an ultimate goal.

The result of this investigation was the development of a concept of high gain, wide-aperture klystron. Experience with pilot devices has shown that the main problem to achieve designed goal was that of self-excitation of the klystron. Traditional technique of suppression of parasitic oscillations proved to be ineffective for a high gain X-band klystrons. In papers [3, 4] we have proposed another idea to suppress parasitic oscillations which consists in the use of RF absorbing drift tubes for distributed suppression of parasitic oscillations. In this paper we present the results of amplification experiments with wide-aperture (15 mm) VLEPP klystron upgraded with RF absorbing drift tubes. We have obtained design output parameters of the klystron and achieved level of 100 MW output power without any evidence of self-excitation.

2 DESIGN OF THE KLYSTRON

Parameters of the klystron are presented in Table 1 and general layout is shown in Fig. 1. Peculiar features of the klystron consist in a high gain, use of PPM focusing system and high ratio $a/\lambda = 0.7$ [5]. Operating voltage of the klystron is 1 MV, operating current – 250 A. Klystron buncher consists of 11 cavities spaced by 64 mm. Output structure is manufactured as corrugated waveguide and operates at $\pi/2$-mode. Total length of the electrodynamic structure is equal to 0.7 m. The design saturation power of 100 MW is achieved at the input power about of 1 W (which corresponds to the power gain about of 80 dB).

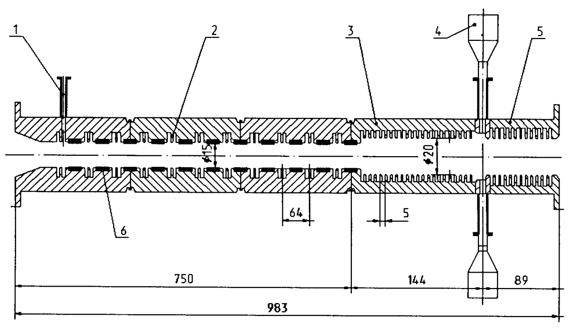

Figure 1: Layout of the klystron with RF absorbing insertions. Here (1) – input waveguide, (2) – resonators of buncher, (3) – output structure, (4) – RF load, (5) – RF filter for E_{01} mode, (6) – RF absorbing insertions (placed inside drift tubes).

Table 1: Parameters of the klystron

General parameters	
Beam voltage	1 MeV
Beam current	250 A
RF frequency	14.0 GHz
Power gain	80 dB
RF peak output power	100 MW
Efficiency	40 %
Focusing system	
Type of magnets	Permanent magnet
Max. Magnetic field	4.5 kGs
Period	64 mm
Number of periods	14.5
Acceptance	0.1π cm·rad
Buncher	
Drift tube diameter	15 mm
Length of drift section	52 mm
Number of drift sections	10
Length of cavity	12 mm
Number of cavities	11
Mode of operation	π
Output structure	
Mode of operation	$\pi/2$
Number of cells	22
Length	110 mm
Aperture	20 mm

The large aperture of drift tubes (15 mm) helps to increase acceptance of the klystron. Nevertheless, there is one harmful consequence of a large aperture – the ground TE_{11} waveguide mode is not cut-off one for this klystron. As a result, the self-excitation of the klystron in the 14 GHz frequency band is occurred due to the positive feedback for TE_{11} mode. Symmetric TM_{010} mode of the buncher and TE_{11} mode are coupled due to the radial misalignment of resonators in the process of their assembling and soldering, as well as due to asymmetric loading of two power outputs.

To solve the problem of parasitic self-excitation, we have developed technology of RF attenuating insertions and placed them inside the drift tubes of the klystron (see Fig.1 and 2). We have studied several methods to obtain absorbing materials. Investigations have shown that glass-carbon materials are more simple for manufacturing and use in our equipment. Such a distributed suppression filter provides significant attenuation of the parasitic modes and does not perturb the klystron operating mode (see Fig.3).

Operating experience has shown that insertions do not affect vacuum conditions and are stable to the heat and radiation load. Investigations of the beam dynamics have not shown any evidence of resistive instabilities of the beam caused by these insertions.

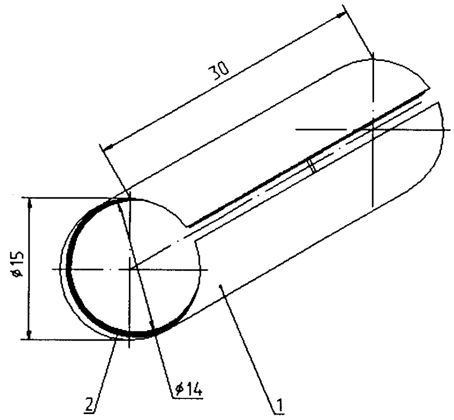

Figure 2: Scheme of RF absorbing insertions. Here (1) – metal foil, (2) – RF absorbing layer.

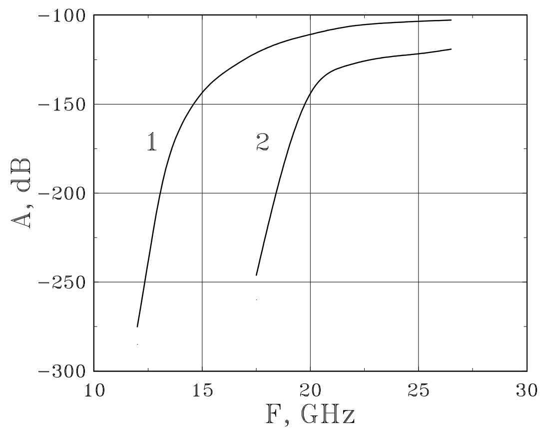

Figure 3: Integral frequency characteristic of the distributed suppression filter composed of ten RF absorbing insertions (1 – H_{11} mode and 2 – E_{01} mode).

3 STUDY OF AMPLIFICATION REGIME

Investigations have been performed at JINR using the driving beam of LIA-3000 induction accelerator (energy 1 MeV, beam current up to 250 A, beam emittance 0.05π cm·rad, pulse duration 250 ns). The beam current monitors provided the possibility to measure the beam current at the accelerator exit, entrance and exit of the klystron and the beam current losses inside the klystron. To obtain a more detailed information about the RF radiation, we have used beam collector in a form of circular waveguide of 20 mm diameter. Measurements have shown that there were no losses of the current in the klystron. The value of the beam current in the collector was 250 A.

The master signal was generated by the travelling wave tube. Typical oscillograms of amplification mode of operation are presented in Fig.4. It is seen from Fig.4a that there are no fluctuations of the beam current in the collector which indicates on the absence of the transverse beam instabilities. We have measured the frequency spectrum of

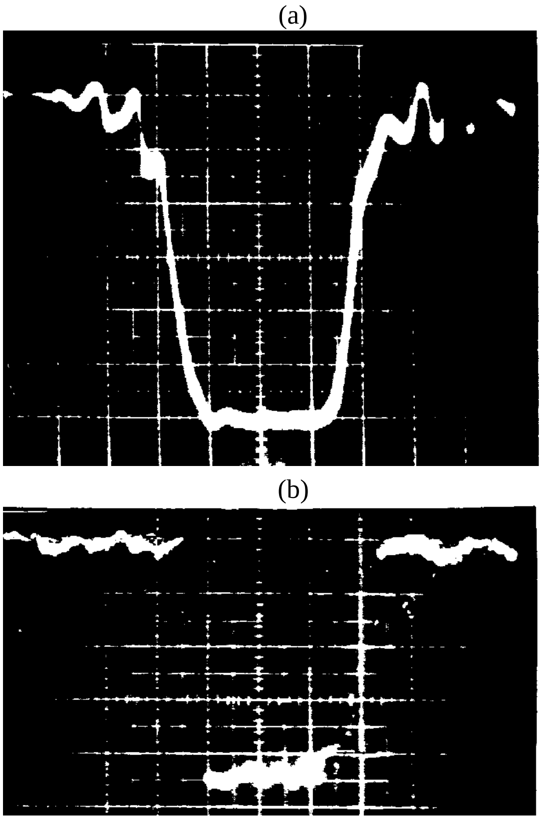

Figure 4: Oscillogram of the amplification regime. Here (a) – the beam current in collector, (b) – RF signal corresponding to 100 MW output power.

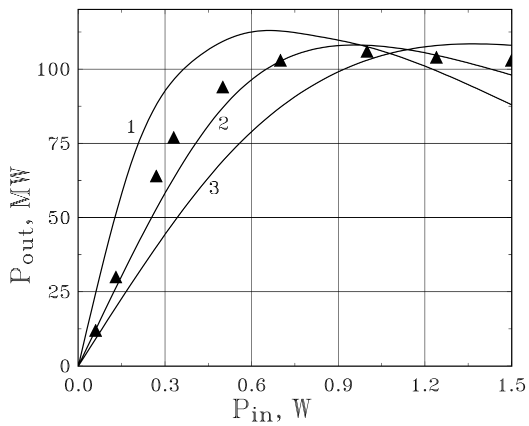

Figure 5: Amplitude characteristic of the klystron. Here ▲ – experimental results and curves – theoretical calculations (1 – $U = 1$ MV, 2 – $U = 1.025$ MV, 3 – $U = 1.05$ MV).

the output radiation and have not observed any frequencies except of operating frequency 14 GHz. In Figs.5 and 6 we present amplitude and frequency characteristics of the klystron. There is good agreement between theoretical and experimental results.

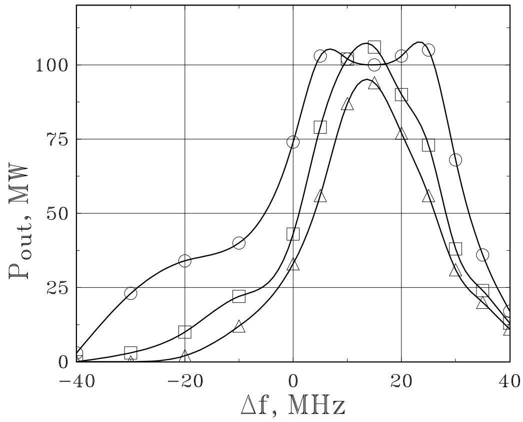

Figure 6: Frequency characteristic of the klystron. Here △ – $P_{in} = 0.5$ W, □ – $P_{in} = 1$ W and ◯ – $P_{in} = 2$ W ($\Delta f = f - 14$ GHz).

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5 REFERENCES

[1] L.N. Arapov et al., Proc. of the 3rd European Particle Accelerator Conference (Berlin, Germany, 1992), Vol.1, p.330.

[2] V.E. Balakin, Proc. of the LC'92 ECFA Workshop on e^+e^- Linear Colliders (July, 25 – August , 2, 1993, Germany), MPI-PhE/93-14, ECFA 93-154, p. 243.

[3] N.I. Azorsky et al., Proc. of the 1994 International Linac Conference (KEK, Japan, 1994, Vol.1, p. 421.

[4] G.V. Dolbilov et al., AIP Conf. Proc. **337**(1994)122.

[5] G.V. Dolbilov et al., "Achieving of 100 MW Output Power in a Wide Aperture VLEPP Klystron with Distributed Suppression of Parasitic Modes", presented at the International Workshop on Pulsed RF Sources for Linear Colliders, Shonan Village, Japan, April 1996.