DESIGN OF 135 MW X-BAND RELATIVISTIC KLYSTRON FOR LINEAR COLLIDER

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Abstract

It has been reported at EPAC-96 Conference on successful experimental results on achievement of 100 MW output rf power in a wide aperture, 15 mm, high gain, 80 dB, 14 GHz VLEPP klystron with distributed suppression of parasitic oscillations [1]. This report presents design of an electrodynamic structure of the X-band klystron for linear collider with a higher efficiency up to 54 % to be achieved at the same parameters of the electron beam ($U = 1$ MeV, $I = 250$ A, emittance 0.05π cm·rad). Design rf output power of the klystron is equal to 135 MW.

1 INTRODUCTION

The cost of RF power system will constitute significant fraction of the total cost of future linear collider. Appropriate design of the klystron can reduce this cost. The focusing system of the klystron should be based on permanent magnets to reduce operational cost. The power gain of the klystron should be high enough to provide an opportunity of using cheap semiconductor devices as master amplifiers. The requirements to the quality of the driving electron beam should also be reduced in order to simplify the design of the gun and the modulator.

2 PARAMETERS OF THE KLYSTRON

A prototype of a high efficiency and low cost X-band klystron is developed by the collaboration of the BINP (Protvino) and JINR (Dubna). Parameters of the klystron are presented in Table 1. Frequency and amplitude characteristics of the klystron are presented in Figs. 1 and 2. Design output rf power is equal to 135 MW. High gain of the klystron, 83 dB at saturation, will allow to use low powerful, 0.6 W, semiconductor master amplifier. The klystron has large aperture of drift tubes, 15 mm ($a/\lambda = 0.7$) which will allow to use relatively low quality driving electron beam from a gridded electron gun.

Focusing system of the klystron is designed on the base of permanent magnets. Output rf system of the klystron is designed to obtain maximal efficiency at reduced value of maximal surface electric field.

Table 1: Parameters of 135 MW VLEPP klystron

General parameters	
Beam voltage	1 MeV
Beam current	250 A
RF frequency	14.0 GHz
Power gain	83 dB
RF peak output power	135 MW
Efficiency	54 %
Focusing system	
Type of magnets	Permanent
Max. magnetic field	0.4 T
rms magnetic field	0.28 T
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
Q-factor of loaded cavity	830
Max. surface field strength	300 kV/cm
Output structure	
Design	expanded conic
Mode of operation	$\pi/2$
Number of cells	22
Length	110 mm
Aperture	15 mm to 20 mm
Max. surface field strength	700 kV/cm
# of power outputs	2

3 BUNCHER

3.1 The choice of the aperture

An increase of the drift tube diameter simplifies the problem of beam transport. On the other hand, a risk of self-excitation of the system is increased. From this point of view, several cases can be identified.

1. The diameter is smaller than the cut-off value for the modes with frequencies less than the double operating frequency. This diameter is a standard choice. At the frequency of 14 GHz the diameter should be less than 6.28 mm.

2. The diameter is less than the cut-off value for the operating frequency. At the frequency of 14 GHz the diameter should be less than 12.56 mm. The diameter of the klystron under development at BINP is equal to

11 mm [2, 4]. In this device the self-excitation occurs at frequencies higher than 16 GHz when the beam current is higher than 100 A.

3. The diameter is larger than the cut-off value for TE-modes (overmoded channel) and less than the cut-off value for TM-modes. At the frequency of 14 GHz the drift tube diameter should be in the range from 12.56 mm to 16.4 mm. The klystron described in this paper belongs to this range.

Positive feedback for TE_{11} leads to the self-excitation of parasitic oscillations near the operating frequency when the drift tube diameter is larger than the critical value for TE-modes. Another mechanism of self-excitation is connected with the synchronous interaction between the electron beam and TE_{11} mode field (beam velocity is approximately equal to a phase velocity of a wave). At the frequencies higher than the critical value for TM-modes there is a risk to get an additional excitation due to these modes.

3.2 The choice of the cavity parameters

The choice of the cavity parameters has been defined by the following suggestions:

1. At a low beam microperveance of 0.25, the Q-factor of loaded cavity is still high, Q = 830. To provide amplification bandwidth up to 40 MHz, it is necessary to have several intentionally detuned cavities.

2. A low beam perveance, a large diameter of the channel and large transit time factor reduce amplification in the cavity. Due to these reasons the number of the buncher cavities should be larger than six.

3. To maintain optimized beam bunching at the beam voltage of 1000 kV, the bunching field should be distributed over several cavities. The requirement to keep the field strength on the cavity surface below 300 kV/cm threshold requires to have at least 3 output cavities.

4. An optimal length of the klystron is about 100 cm. On the other hand numerical simulations shows that an increase of the klystron length from 70 cm to 100 cm leads to the efficiency increase less than 5 %.

Due to these reasons the bunching unit length in our klystron is equal to 70 cm and the number of the cavities is equal to 11.

To improve the bunching characteristics of the klystron the cavities of the wide aperture buncher are designed as two-gap π-mode cavities which provide better transit time factor.

One more detrimental factor of the larger diameter of the drift tube is the dependence of the bunching properties of the cavity on the radius of the electron beam. This circumstance might have a strong effect in the case of a nonrelativistic beam. In our case, however, the dependence on the radius is reduces significantly because of using relativistic beam [6].

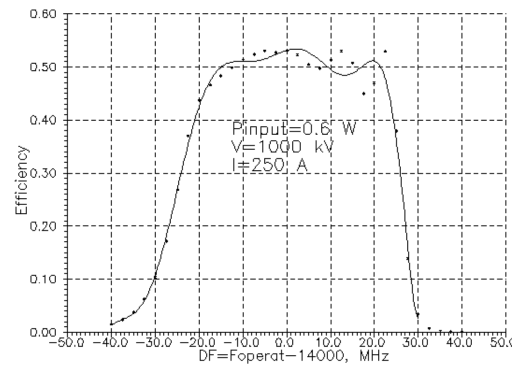

Figure 1: Frequency characteristic of the klystron.

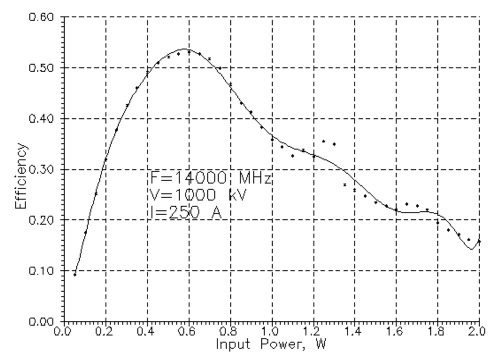

Figure 2: Amplitude characteristic of the klystron.

4 FOCUSING SYSTEM

Focusing system of the klystron is designed on the base of permanent magnets. The magnetic field has been calculated with two-dimensional codes and measured afterwards in a real device. The electron beam transport through such a system has been optimized using numerical simulations taking into account angular spread of the electron velocities and the space charge fields. The results of these simulations are presented in Fig. 3.

5 OUTPUT STRUCTURE

The design of the output system has changed with respect to previous one [3]. At present it is manufactured in a form of a segment of expanding conic diaphragm waveguide with the mode of oscillations close to $\pi/2$. The aperture of the output structure is increased from 15 mm at the entrance up to 20 mm at the exit. Such a design correspond to higher impedance and higher efficiency, up to 54 % (previous design provided efficiency of 44 % [3]).

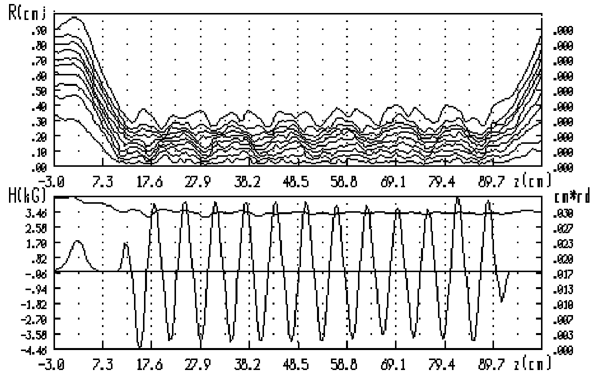

Figure 3: Magnetic field of the klystron and numerical simulations of the electron beam transport.

Symmetrical design of two rf power outputs improves conversion efficiency of operating TM-mode of the output structure into TE-mode of the output waveguide. To prevent penetration of the rf field to the electron beam collector, the transit section between the power output and the collector is installed. It has appearance of a segment of an irregular diaphragm waveguide with the suppression band of the filter at the frequency of 14 GHz (plug-type filter).

To increase the reliability of the klystron, the elements of the output structure where the electric field strength exceeds 300 kV/cm are manufactured of stainless steel. The surfaces of the stainless steel insertions are strengthened mechanically and shined. We suppose that such a technology will provide a safe margin of operation up to maximal electrical field strength on the surface of 700 kV/cm.

6 SUPPRESSION OF PARASITIC OSCILLATIONS

To suppress parasitic oscillations we use the technique of RF absorbing insertions installed inside the drift tubes [4, 7]. We have studied several methods to obtain absorbing materials. Investigations have shown that glass-carbon and ”SiC” materials are more suitable for this applications.

Such a distributed suppression filter provides significant attenuation of the parasitic modes and does not perturb the klystron operating mode (see Fig.4). Operating experience has shown that materials 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 [8].

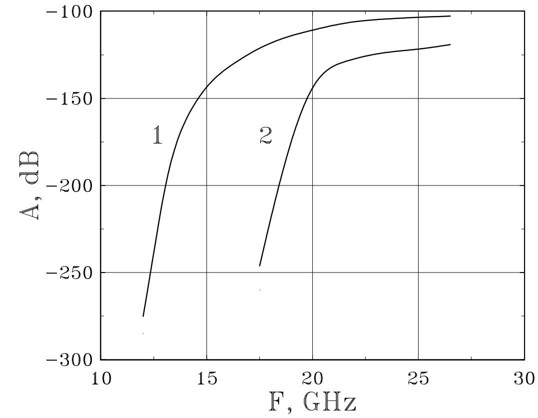

Figure 4: Integral frequency characteristic of the distributed suppression filter composed of ten RF absorbing drift tubes (1 – H_{11}-mode and 2 – E_{01}-mode).

7 REFERENCES

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