STUDY OF THE 14 GHZ RELATIVISTIC KLYSTRON FOR VLEPP

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Abstract

Results of experimental study of relativistic klystron for VLEPP are presented. Investigations have been performed using the driving beam of the JINR LIA-3000 induction accelerator ($E = 1$ MeV, $I = 300$ A, $\tau = 250$ ns). The main emphasis is put on the study of the self-excitation parasitic modes and their temporal evolution. A concept of relativistic klystron with distributed suppression insertions is proposed to solve the problem of the parasitic oscillations suppression.

Introduction

Designers of the X-band klystrons for linear colliders face two conflicting problems. First, the klystron should produce a high output power ($\sim 50-100$ MW) which requires the aperture to be rather large to provide a high value of the operating current. Second, parasitic modes of oscillation should be suppressed. The first requirement puts a strong limitations of the minimal admissible klystron aperture. As a result, the frequencies of parasitic modes become quite close to the operating frequency and their increments grow with the beam current which makes the problem of the parasitic oscillation suppression to be more complicated.

We have studied two ways to solve the problem of the parasitic modes suppression, namely the use of the technique of wave chokes and the technique of permanent change of the phase velocity of the parasitic modes to decrease the interaction of the beam with parasitic modes. Nevertheless, our experience have shown that these techniques do not provide the desired results, especially in the case of a high gain ($\sim 70-80$ dB).

Another idea to suppress parasitic oscillations is to find such a klystron design where the increments of parasitic modes are less than their attenuation in the klystron. To realize this idea, we have developed the concept of relativistic klystron with distributed suppression insertions placed inside the drift spaces. Experiments with such a klystron have confirmed the validity of the idea and the output parameters close to those required have been obtained.

Experimental setup

We have studied the variant of the 14 GHz VLEPP klystron with variable diameter of the drift tubes (see Table 1 and ref. [1]). Investigations have been performed at JINR using driving beam of LIA-3000 induction accelerator (energy 1 MeV, beam current 200 – 300 A, beam emittance 0.05π cm·rad, pulse duration 250 ns). The beam was matched with the klystron magnetic system by means of focusing lenses and the cone Ti diaphragm of 10 mm diameter was placed prior the klystron entrance. The beam current monitors provide the possibility to measure the beam current at the acceleartor 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 several beam collectors in a form of circular waveguides of 15 – 20 mm diameter. There was a possibility to control the axial position of the collector.

TABLE 1
Parameters of the VLEPP Klystron

General parameters	
Beam voltage	1 MeV
Beam current	300 (150) A
RF frequency	14.0 GHz
Power gain	70 dB
RF peak output power	165 (45) MW
Efficiency	55 (30) %
Focusing system	
Type of magnets	Permanent
Max. Magnetic field	4.5 kGs
Period	64 mm
Number of periods	10
Acceptance	0.08π cm·rad
Buncher	
Drift tube diameter (variable)	11 – 12.05 mm
Length of drift section	59 mm
Number of drift sections	7
Length of cavity	5 mm
Number of cavities	8
Output structure	
Mode of operation	$2\pi/3$
Number of cells	10
Length	75 mm
Aperture	16 mm

Study of focusing system

To study of the beam dynamics in the focusing system we have screened the beam from the electromagnetic structure of the klystron by a thin tube. Measurements have shown that the focusing stricture was manufactured with appropriate accuracy. At 210 A of the accelerator current, about of 8 – 10 A was lossed at the cone diaphragm, and there were no losses of the current in the buncher and the output structure. The beam envelope in the klystron was in good agreement with calculations.

Study of self-excitation regime

The self-excitation regime has been examined in three stages: study of the self-excitation modes of buncher (at screened output structure); the study of the self-excitation modes of output structure (at screened buncher) and the study of the self-excitation modes of klystron.

Frequency measurements have shown that there are several frequency bands of parasitic modes. The self-excitation of the buncher takes place at frequencies

$$18.40\ \text{GHz} \lesssim f \lesssim 18.80\ \text{GHz}, \qquad f_1 = 18.60\ \text{GHz}$$
$$19.68\ \text{GHz} \lesssim f \lesssim 19.80\ \text{GHz}, \qquad f_2 = 19.74\ \text{GHz}$$
$$20.12\ \text{GHz} \lesssim f \lesssim 20.28\ \text{GHz}, \qquad f_3 = 20.20\ \text{GHz}$$
$$20.80\ \text{GHz} \lesssim f \lesssim 21.00\ \text{GHz}, \qquad f_4 = 20.90\ \text{GHz}$$

and their harmonics. The output structure is self-excited at frequencies:

$$15.7\ \text{GHz} \lesssim f \lesssim 16.0\ \text{GHz}, \qquad f_5 = 15.85\ \text{GHz}$$

and their harmonics.

The self-excitation spectrum of the klystron is a simple combination of the self-excitation spectra of the buncher and output structure. The frequencies of the self-excitation bands depend on the beam voltage and the beam current. The modes of the $f_1 = 18.6$ GHz frequency band have maximal increments and the self-excitation mode of the output structure – the minimal one. Within limitations of the pulse duration (250 ns) we have not obtained a threshold behaviour of the self-excitation. At a high beam current it takes place at the beginning of the pulse and when the current is decreasing, a detectable amplitude of the self-excitation occurs at a longer time from the pulse beginning.

More thorough investigations have shown a complicated temporal behaviour of the self-excitation regime. In Fig.1 we present a typical oscillograms. It is seen from Fig.1a that there are significant fluctuations of the beam current in the collector. This is connected with the fact that there are significant losses of the current in the klystron and indicates the existence of transverse beam instabilities. Fig.1b and 1c show the dependency on time of the output klystron power obtained by the wide band and narrow band detectors, respectively. These pictures indicate that the self-oscillation spectrum is not fixed but evolves significantly in time. Thorough frequency measurements performed with tunable narrow band detector have shown that the self-excitation process has appearance of a mode competition process. The self-excitation develops from one mode with some frequency and then it gives birth to another modes with another frequencies. Next, these new modes grow and suppress "parent" mode, etc.

Presence of the signal from master oscillator (TWT) does not change the situation. At low beam current ($I \lesssim 50$ A) we have obtained nominal regime of amplification. When the beam current was increased, the self-excitation occured at the back front of the beam current and the the duration of the amplification stage shortened with the beam current increase. At the beam current value about of 250 A the self-excitation process occured from the beginning of the pulse.

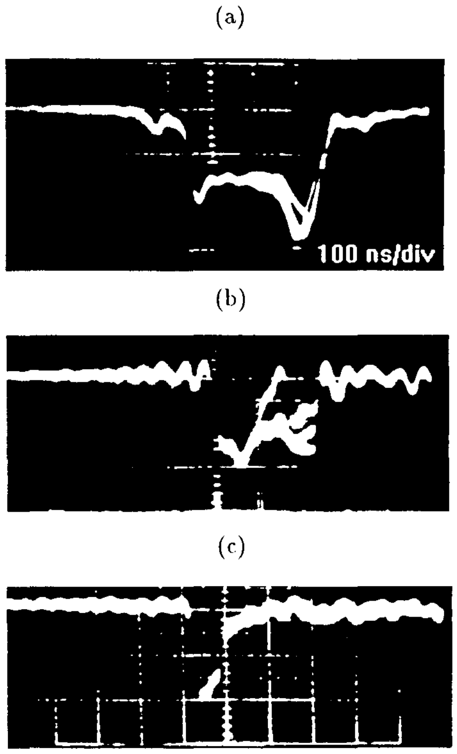

Fig. 1: Oscillogram of the self-excitation: (a) - the beam current in collector, (b) - RF signal from the wide band detector, (c) - RF signal from the narrow band detector.

Concept of klystron with distributed suppression insertions

So, the problem is arisen to suppress self-excitation of the klystron. It should be noted the results of the self-excitation study presented in the previous section have been obtained with the klystron where special precautions have been undertaken to suppress the parasitic modes. Namely, the drift tubes of this klystron have a variable diameter to provide the variable phase velocity along the klystron of the parasitic modes thus reducing their interaction with the electron beam.

To overcome the self-excitation problem, in this paper we propose a concept of the klystron with distributed suppression of parasitic modes. The main idea of this concept is to find such a klystron design where the increments of parasitic modes are less than their attenuation in the klystron. We have realized this concept in the following way. We have developed technology of attenuating insertions and placed them inside the drift sections of the klystron. Such a distributed suppression filter provides significant attenuation of the parasitic modes and do not perturb the klystron operating mode (see Fig.2).

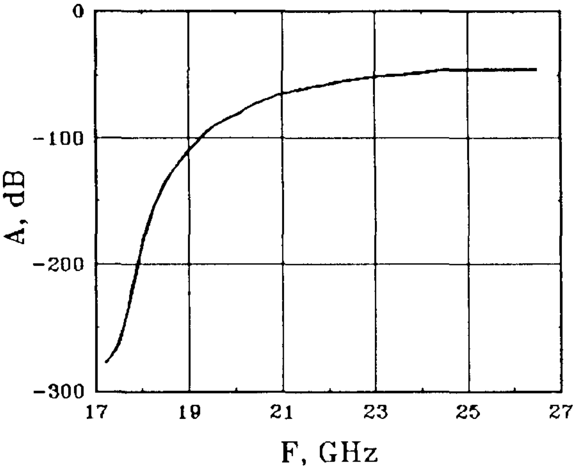

Fig. 2: Frequency characteristic of the distributed suppression filter

Operating experience has shown that insertions do not affect vacuum conditions and are stable to the action of the heat and radiation load.

We have expected also that the insertions may cause resistive instabilities of the beam. Nevertheless, thorough investigation of the beam dynamics has not shown any evidence of such instabilities.

In the same way as it has been described in the previous section, we have performed the study of the self-excitation mode of operation. It was found that all parasitic modes of the buncher self-excitation have been totally suppressed.

Study of amplification regime

We have performed study of amplification regime with the master signal from the travelling wave tube. Typical oscillograms of amplification mode of operation are presented in Fig.3. It is seen from Fig.3a 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 the output radiation and observed the presence of the self-excitation mode of the output structure ($f_5 = 15.85$ GHz). Nevertheless, its amplitude was extremely weak and it did not affect the amplification mode of operation.

At the beginning of operation with a high output power we have obtained that the RF pulse is shorter than the beam current pulse. This was connected with the RF discharges in the output structure and output RF transformer. During RF training the RF pulse became to be longer (see Fig.3b) and after that we have increased gradually the value of the operating current or amplitude of master signal. At the beginning of the next training cycle the amplitude of the RF output power was increased, while the RF pulse was shortened (see Fig.3c) and the RF training procedure was repeated again. At the time of the preparation of this paper, the process of RF training was not completed yet. We have achieved the value of the output RF power about of 45 MW at the beam current $I \sim 150$ A which corresponds to the klystron efficiency ~ 30 %. This result is in good agreement with calculations.

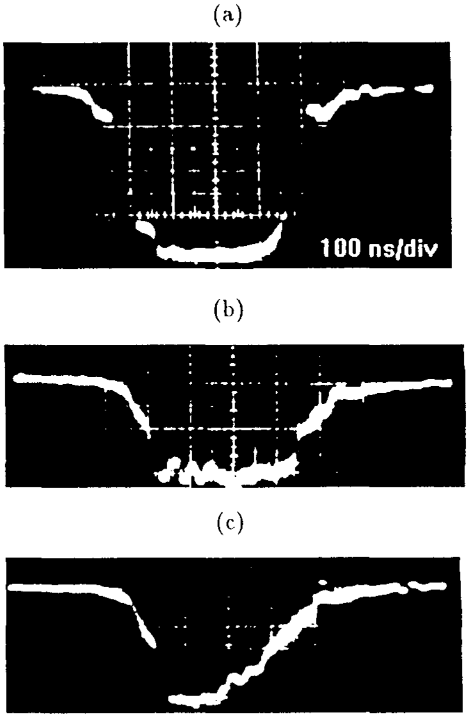

Fig. 3: Oscillogram of the amplification regime: (a) - the beam current in collector, (b) - RF signal after RF training cycle, (c) - RF signal at the beginning of the next RF training cycle

Conclusion

In this paper we have proposed the concept of the klystron with distributed suppression of parasitic modes and its validity has been confirmed experimentally. We believe that such an approach to the klystron design will be extremely fruitful and can form a novel direction in the design of short RF wavelength klystrons.

References

[1] N.I. Azorskiy et al., "VLEPP Klystron Activity at Dubna", Proc. of the International Workshop on Pulsed RF Power Sources for Linear Colliders (July 5-9, 1993, Dubna, Russia), p.143