TWO-FREQUENCY KLYSTRON AMPLIFIER

A.N. Dovbnya, Yu.D.Tur
NSC-KPTI, Kharkov, Ukraine
V.E. Rodyakin, A.N. Sandalov
MSU, Moscow, Russia

Abstract

The necessity to create the RF sources operating in two-frequency mode is supported by the proposals concerning the suppression of the emittance growth generated inside the RF gun [1] and the possibility to increase the limited accelerated charge [2] by involving into the interaction with the beam, in addition to the fundamental harmonic, the highest harmonics of a RF field with the power ratio up to 10 : 1 and the absolute synchronism of changing phase and amplitude ratios of signals. In this paper we present the preliminary results on studying the possibilities of multiple-frequency RF power generation by a single klystron through installation of a supplementary high harmonic cavity into the exit one after the main output cavity along the beam direction. The physical motivation of the proposal consists in the effect of lengthy bunch rearrangement due to the interaction with the high-strength RF fields. The computer simulation results and experimental data are given.

Introduction

One of the fundamental problems of the physics of accelerators is the one of increasing the accelerated beam current. As is known, the main limits for the permissible accelerated charge values are caused, first of all, by the beam emittance blow up in the injector systems and by the increase of radiated fields amplitude, including that of HEM-type in the accelerating structures. The apparent method to enhance the limited accelerated charge consists in the decrease of the charge density in bunches by increasing their phase length. In this case the emittance growth suppression in the RF injectors can be provided by the multi-frequency operation mode of the RF gun cavity [1] or with a single-mode RF gun, including the correcting cavity in the injector setup. The identical condition for acceleration of all the particles in the lengthy bunch, when the level of radiation fields is considerably decreasing with the form-factor value decrease, can be obtained in the multi-mode acceleration regime in the resulting RF field of a "rectangular" form [2]. In particular, the same is performed in the accelerating interval of proton synchrotrons for widening the region of phase stability and lowering the space charge effect [3]. In both cases one of the most important problem of a practical realization is the generation of absolutely synphase RF fields of sufficiently high levels at multiple frequencies.

In this paper presented are the preliminary results on studying the possibilities of multiple-frequency RF power generation by a single klystron through installation of the supplementary high-harmonic cavity into the exit one after the main output cavity along the beam diraction. The physical motivation of the proposal consists in the effect of lengthy bunch rearrangement due to the interaction with the high-strength RF fields.

The Previous Design

It is obvious that during interaction of the bunches of a large phase length with the field of the output cavity, when the total time of interaction is more than a half of RF oscillation period, one part of particles in the bunch is accelerating. In the further passing of the drift space the possibility exists of outflying the main braked part of bunch ("flipping" effect). As a result, the beam may be rearranged so that instead of one bunch formed by the field of a fundamental frequency there will be two flying away bunches in the flow.

It is clear that changing the length of the drift tube one can attain the multiplicity to the wave length in the location of these bunches, i.e. to provide the beam modulation at the multiple frequencies.

Previously, we observed this effect investigating the beam parameters at the bunching system exit of the klystron ("Aurora"-type: 2.797 GHz; 20 MW; 35 % efficiency) [4]. The investigations were performed by a well-known method of reconstruction of the modulated flow structure on a level of spectral components of the output RF power with changing the length of the drift tube. The general view of the installation is shown in Fig.1.

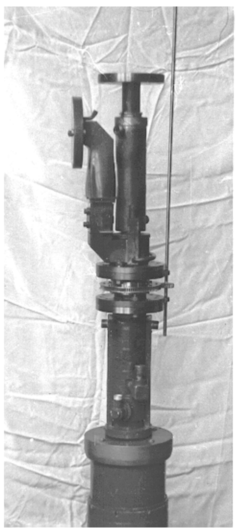
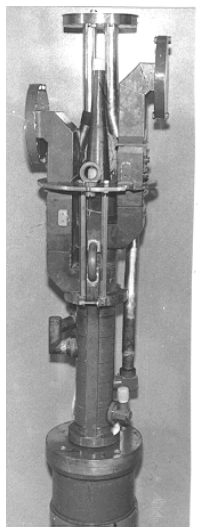

Fig.1. The general view of experimental klystrons with the variable length of the end drift tube (left) and with the additional output cavity (right).

The effect of resonance excitation of the second harmonic signal depending on the space length was discovered (Fig.2).

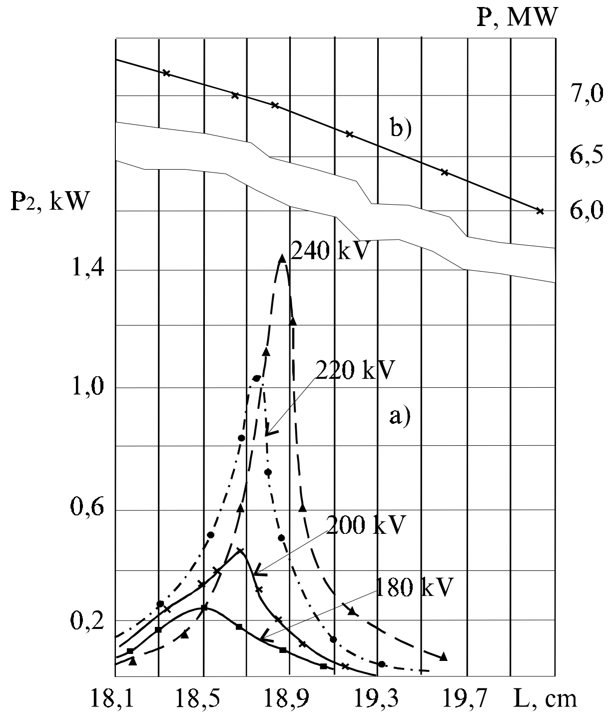

Fig.2. The pulse output power at the frequency of second harmonic as a function of the length of the latter drift space for various anode voltage (a); the output power at the freqency of fundamental harmonic as a function of the drift space for the anode voltage 200 kV (b).

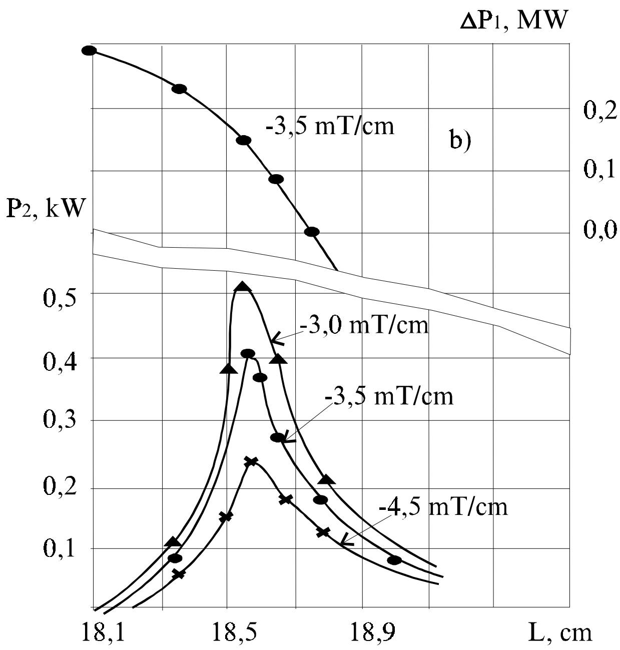

Fig.3. The pulse output power at a frequency of the second harmonic (a) and the level of fundamental mode power increase (b) as a function of the length of the end drift space (anode voltage 211 kV, beam microperveance 1.05 and various values of the magnetic field fall off along the axis).

The increase of the negative gradient of the focusing field in this space region has resulted in decreasing the amplitude of the excited signal at the second harmonic frequency (Fig.3) and simultaneously the small increasing the power level at the fundamental frequency mode. The effect of the power inccrease at the fundamental mode was observed for the magnetic field gradient values within the limits of the situation where the low energy component of the beam is removed onto the drift space wall and the main bunch is passed into the output cavity [5].

Investigation of the characteristics of a RF field excited by the beam in the supplementary output cavity, identical to the main one and installed after it (see Fig.1), has shown besides the other effects, the considerable increase of the second harmonic level signal as compared to the base model of klystron.

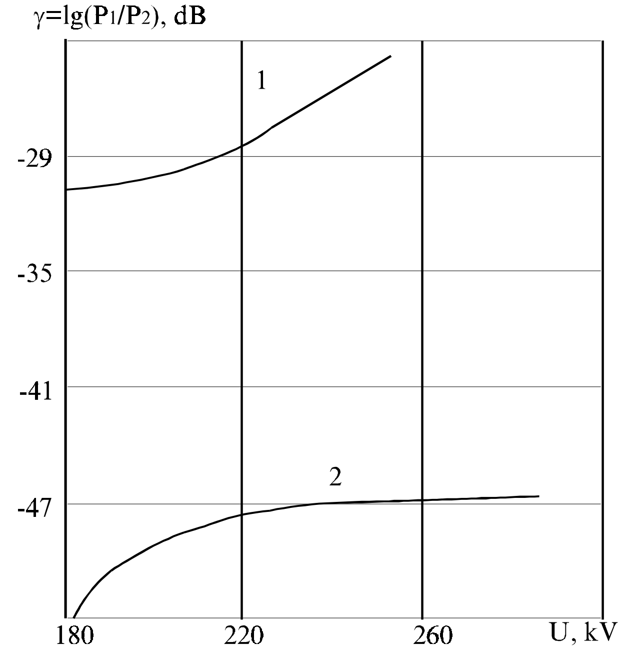

Fig.4. The relative level of the second harmonic power as a function of the anode voltage in the supplementary output cavity (curve1) and at the exit of a standard klystron (curve2).

In our opinion the presented data indicate conclusively on the existence of the effect of an electron bunch rearrangement in the high power amplifiers and confirm the possibility of creating the two-mode operation RF sources.

Computer Simulation

In order to check the second beam current harmonic Laval after the output cavity, the 2.5D Particle-In-Cell ARSENAL-MSU code [7] has been applied to B-Factory Linac 50-MW pulse klystron PV3050, which has been developed at KEK [8]. Because of the mass production, the tube performances were carefully studied, and detailed information is available on this tube. Therefor this tube is a good example for theoretical study of high harmonic energy extraction from spent electron beam in klystron. This tube produces 51 MW

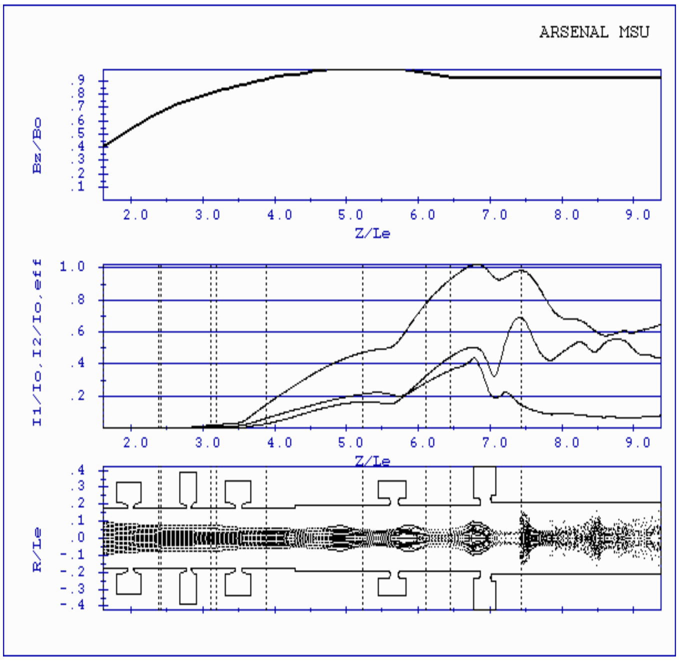

Fig.5. The magnetic field distribution (upper), fundamental and the second harmonic beam current distribution and electronic efficiency (middle) and momentary photo of electrons (lower) downstream the klystron (z/Le - the normalized distance, Le - the electron wave length).

at a 310 kV beam voltage with efficiency 47% at saturation. But theoretical investigations had show that significant second harmonic beam current Laval can be reached not for optimal regime. So calculations were made for input power 100W, which is bellow saturation.

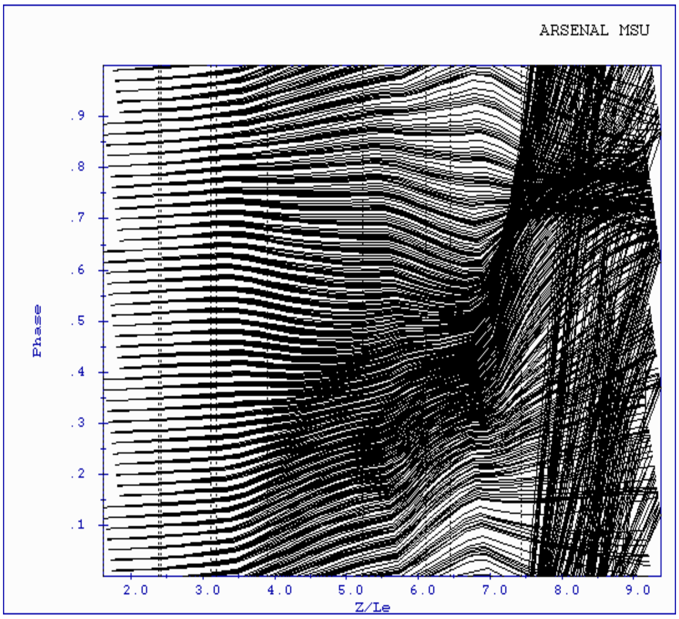

Fig.6. Phase diagram

The electron beam propagation along the buncher is presented on Fig. 5. On the upper slide the magnetic field (Bz/Bo) distribution is presented. The fundamental and the second harmonic beam current distribution and electronic efficiency (middle slide) and momentary photo of electrons (lower slide) downstream the klystron are shown. Two bunches on the one electron wavelength with different density after the output cavity can be seen on this slide.

The electron beam bunching in normalized (over 2π) phase diagram from the longitudinal coordinate z/Le is presented on Fig.6. Obtained efficiency 33% corresponds to output power 37 MW. Second beam current harmonic Laval 0,7 from fundamental current is quite high for receiving high RF power on the second harmonic. This value allow to extract from spent beam second harmonic power near 5 - 10 MW.

Conclusion

The foregoing experimental data and numerical simulation results indicate on the real possibility of creating the high-power klystron amplifier with simultaneous generation of the signal at fundamental and multiple frequency. In turn, the existence of such a RF source can provide the certain progress in the field of accelerators development.

Acknowledgment

The authors would like to express their gratitude to Dr. S. Fukuda for the data on the PV3030 klystron parameters to be used as a base model in the numerical simulation.

References

[1] L. Serafini, ”Beam Dynamics in RF Guns and Emittance Correction Techniques”. NIM, A (340), p40 (1994)
[2] Yu. D. Tur, “On Enhancement of Limited Accelerating Charge”. Proc. 1995 PAC and Int. Conf. on High-Energy Accel., Dallas, p990 (1995)
[3] L.Z. Barabash et al., “Enhancement of Particle Capture in Proton Synchrotron by Adding the Second Harmonic to the Accelerating Field”. Proc. of All-Union Seminar on Charge Particle Accel., Moscow, vol.2, p123 (1968) (in Russian)
[4] A.N. Dovbnya, N.S. Repalov, Yu.D. Tur, “The Mechanism of Excitation of a Second Harmonic Signal in the Multicavity Klystron”. Electron. Techn., Issue “RF Electronics”, 3(363), p3 (1984) (in Russian)
[5] A.N. Dovbnya, A.I. Martinov, Yu.D. Tur, “The Relativistic Klystron”. Patent # SU 1259880 description (1987) (in Russian)
[6] A.N. Dovbnya, N.S. Repalov, Yu.D. Tur, “Defocusing of the Modulated Electron Flow in the Region of Longitudinal Magnetic Field Falloff”. VANT, Kharkov, 2(18), p64 (1984) (in Russian)
7. V.E.Rodyakin, A.N.Sandalov,”Computer Codes for Electron Beams Dynamics at Klystron”. Problems of Electronic Technics, Saratov, Politechnical Inst. Press, p28(1988)
8. S.Fukuda at al.,”Development of the B-Factory Linac 50 MW Pulse Klystron’. KEK Preprint 94-108 (September 1994)