EFFECT OF GENERATION OF MULTIPLE-FREQUENCY RF POWER IN THE O-TYPE TUBE

A.N. Dovbnya[1], Yu.D. Tur[1], V.E. Rodyakin[2], A.N. Sandalov[2]
[1]National Science Center "Kharkov Institute of Physics and Technology", Kharkov, Ukraine
[2]Physics Department, M.V. Lomonosov Moscow State University, Moscow, Russia
E-mail: tur@kipt.kharkov.ua

The necessity to create the RF sources operating in the multifrequency mode is supported by the proposals concerning the suppression of the emittance growth generated inside the RF gun and the possibility to increase the limited accelerated charge 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 supplementary high harmonic cavities to 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 decelerating RF fields. The previous experimental data, the 2.5D Particle-In-Cell ARSENAL-MSU code concise description and computer simulation results are given.

PACS: 84.30.Jc

1. 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 problems of a practical realization is the generation of absolutely cophased 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 cavities 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 decelerating RF fields in the output cavities.

2. THE PREVIOUS EXPERIMENTAL RESULTS

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 outgoing 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.

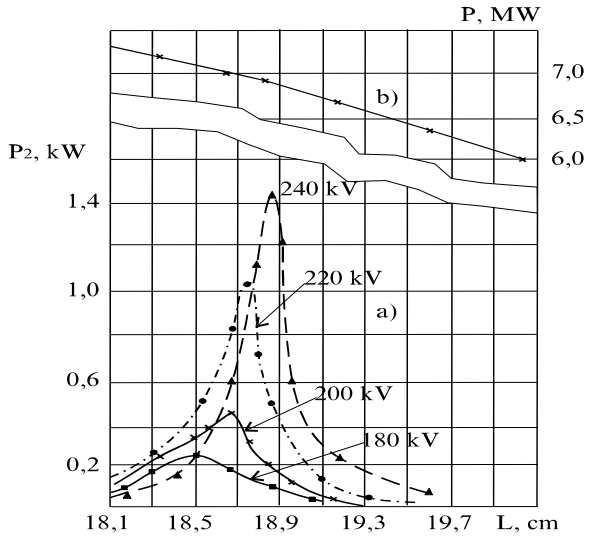

Fig.1. The pulse output power at the frequency of second harmonic as a function of the length of the latter drift space for various anode voltage (a); the output power at the frequency of fundamental harmonic as a function of the drift space for the anode voltage 200 kV (b)

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

ВОПРОСЫ АТОМНОЙ НАУКИ И ТЕХНИКИ. 2008. № 4.
Серия: Плазменная электроника и новые методы ускорения (6), с.312-315.

output RF power with changing the length of the drift tube. The effect of resonance excitation of the second harmonic signal depending on the space length was discovered [5] (Fig.1).

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.2) and simultaneously the small increasing the power level at the fundamental frequency mode. The effect of the power increase 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 [6].

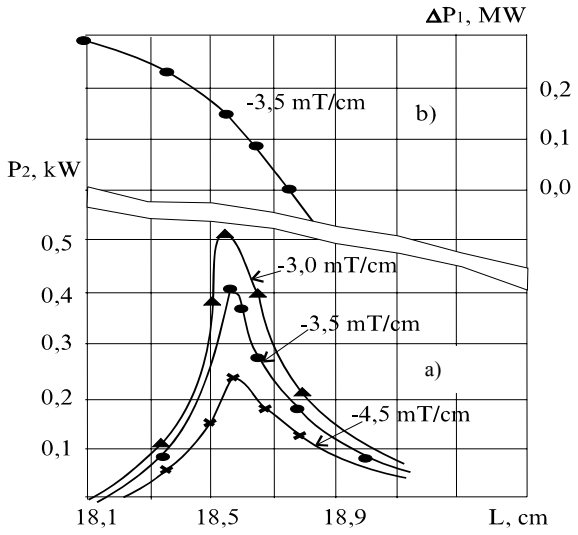

Fig.2. The pulse output power at a frequency of the second harmonic (a) and the level of fundamental mode power increase (b) as a function of the length of the end drift space (anode voltage 211 kV, beam microperveance 1.05 and various values of the magnetic field fall off along the axis)

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, as shown besides the other effects, the considerable increase of the second harmonic level signal (by two order of magnitude greater) as compared to the base model of klystron.

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 multimode operation RF sources.

3. COMPUTER CODE DESCRIPTION

It means that there are no possibilities for the direct application of existing computer codes for understanding the physics of intense electron beam energy conversion to electromagnetic radiation energy in view of space-charge density dynamics from electron gun to collector. Therefore it is necessary use a new physical ideas and a new numerical methods, including in self of achievement from adjacent areas of knowledge. Also these new ideas must be checked very carefully by experimental study.

The analysis of interaction between charged particles and EM fields of electrodynamics systems embodies a mutual solution of the boundary-value problem for Maxwell's field equations and equations of motion for a single particle. The expansion of the field by the modes of irregular systems (as cavity one) turns to be sometimes impossible. So most of the models are based on the representation of electrodynamics systems as equivalent circuits (port approximation). Note that simulation the motion of charged particles comes to be extremely difficult if Coulomb interactions are not omitted. Anyway, it can be done using the method of "large" particles, which treat the electron's flow as a set of single groups of electrons. In the case of 1D disk computer codes ("Disk", "Japandisk", "Tube O" and etc.) of the electron beam one can calculate Coulomb interaction between particles and some estimates concerned the overtaking one particle by the other one can be established. The application of 1.5D disk-ring code (which takes into account the "stratification" effects) provides the description of some 2D phenomena (such as potential depression, radial dependencies of the EM fields in the cavities and radial dependence of space charge forces).

To realize the high efficiency in klystron is possible only under careful analysis of non-linear interaction phenomena in all parts of klystron: electron gun, linear and non-linear bunchers, output circuit and collector. For this purposes the computer codes "Klystron-MSU", "Arsenal-MSU" and "Multiwaves-MSU" were developed on Physics Department at MSU. "Klystron-MSU" is 1-1.5D disk-ring code of electron beam and is used as the first step of klystron calculation. The 2.5D PIC code "Arsenal-MSU" [7] allows to analyze klystrons, containing thermionic and field-emission electron guns, linear and non-linear bunchers, distributed output structures, conventional and depressed collectors. This code is based on the self-consistent analysis of charged particles dynamics in electromagnetic fields, representation of electron beam by large particles and modified Galerkin's method for Maxwell equations solution. So the "Arsenal-MSU" code used for the computer simulation of high power high efficiency klystrons from cathode to collector with knowledge just geometry of the device. The computer code "Multiwaves-MSU" developed for investigation of dispersion characteristics of EM and electron waves, EM fields structures, problems connected with RF breakdown and self-excitation of parasitic oscillations in output circuit as a diaphragm waveguide. All these codes were used for high efficiency conventional klystrons developed in USSR and were tested at KEK and Thomson Tubes Electronique" and show the good agreement with the experimental data.

In particular the validity of the ARSENAL-MSU computer code has been checked on the famous high efficiency CW klystron TH2089.

The Fig.3 shows the experimental and calculated by ARSENAL-MSU code efficiency versus drive power for this klystron. The agreement is quite good. ARSENAL-MSU computer code calculations present electronic efficiency value but experimental data correspond to overall tube efficiency. This fact explains difference near 5% in the efficiency value at the saturation level.

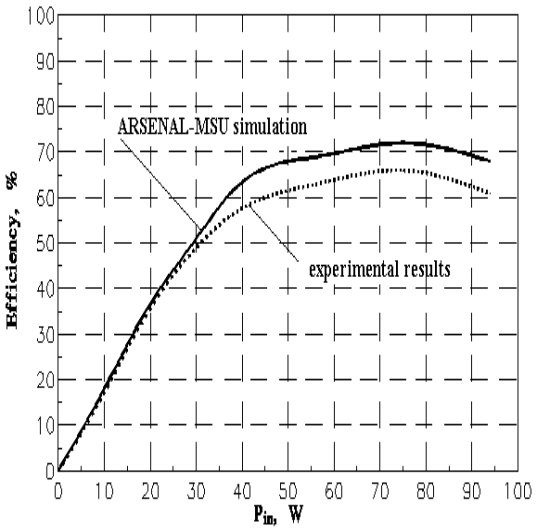

Fig.3. Comparison of ARSENAL-MSU calculations and experimental data for TH2089

4. SIMULATION RESULTS

In order to check the second beam current harmonic level after the output cavity, the 2.5D Particle-In-Cell ARSENAL-MSU code has been applied to B-Factory Lilac 50-MW pulse klystron PV3050, which has been developed at KEK [8]. This tube produces 51 MW at a 310 kV beam voltage with efficiency 47% at saturation. But theoretical investigations had show that significant second harmonic beam current level can be reached not for optimal regime. So calculations were made for input power 100 W, which is bellow saturation.

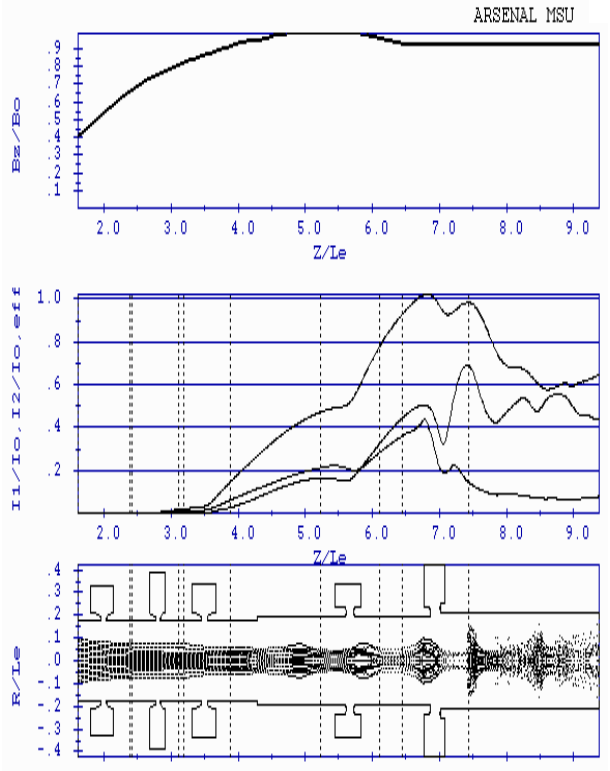

Fig.4. The magnetic field distribution (upper), fundamental and the second harmonic beam current distribution an electronic efficiency (middle) and momentary photo of electrons (lower) downstream the klystron (z/Le - the normalized distance, Le - the electron wave length)

The electron beam propagation along the buncher is presented on Fig.4. 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 is 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.5.

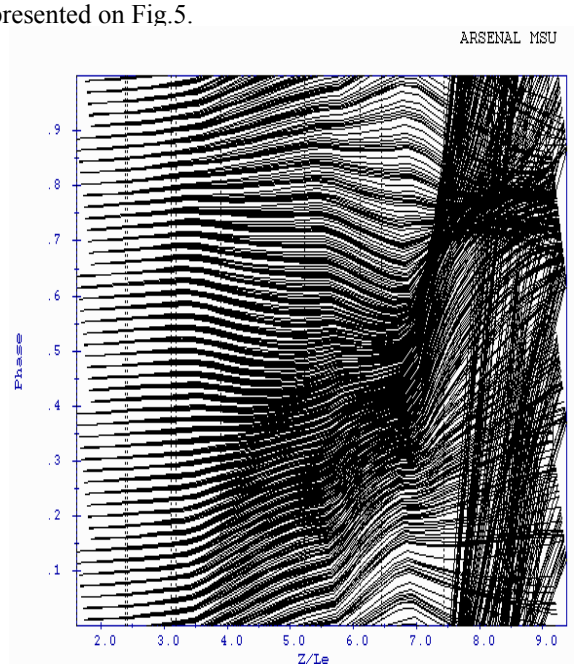

Fig.5. Phase diagram

Obtained efficiency 33% corresponds to output power 37 MW. Second beam current harmonic level 0,7 from fundamental current is quite high for receiving high RF power on the second harmonic. This value allows extracting 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 frequencies. In turn, the existence of such a RF source can provide the certain progress in the field of accelerators development.

REFERENCES

1. L. Serafini. Beam Dynamics in RF Guns and Emittance Correction Techniques // *NIM*. 1994, v.A340, p.40-47.
2. Yu.D. Tur. On Enhancement *of* Limited Accelerating Charge // *Proceeding of the 1995 Particle Accelerators Conference*. 1995, v.1, p.990-993.
3. L.Z. Barabash, et al. Enhancement of Particle Capture in Proton Synchrotron by Adding the Second Harmonic to the Accelerating Field // *Proceeding of All-Union Seminar on Charge Particle Accelerators*. 1968, v.2, p.23-26.
4. A.N. Dovbnya, A.I. Marlinov, Yu.D. Tur. The Rela-

tivistic Klystron // *Patent № SU 1259880 description.* 1987.
5. A.N. Dovbnya, N.S. Repalov, Yu.D. Tur. The Mechanism of Excitation of a Second Harmonic Signal in the Multicavity Klystron // *Electronnaya Technika, Issue "RF Electronics".* 1984, №3(363), p.3-7.
6. A.N. Dovbnya, N.S. Repalov, Yu.D. Tur. Defocusing of the Modulated Electron Flow in the Region of Longitudinal Magnetic Field Falloff // *Problems of Atomic Science and Technology. Series "Nuclear Physics Investigation".* 1984, №2 (18), p.64-67.
7. V.E. Rodyakin, A.N. Sandalov. Computer Codes for Electron Beams Dynamics at Klystron // *Problems of Electronic Techniques.* 1988, v.7, №1, p.28-36.
8. S. Fukuda, et al. *Development of the B-Factory Linac 50 MW Pulse Klystron*: KEK Preprint 94-108, 1994.

Статья поступила в редакцию 19.05.2008 г.

ЭФФЕКТ ВОЗБУЖДЕНИЯ ВЫСОКОЧАСТОТНОЙ МОЩНОСТИ НА КРАТНЫХ ЧАСТОТАХ В ПРИБОРАХ О-ТИПА

А.Н. Довбня, Ю.Д. Тур, В.Е. Родякин, А.Н. Сандалов

Необходимость создания СВЧ-источников, работающих в режиме одновременной генерации мощности на гармониках кратных частот, в частности определяется задачами физики ускорителей, такими как подавление эффекта возрастания эмиттанса в инжекторах с ВЧ-пушками и увеличение предельного ускоренного заряда. Это может быть осуществлено путем включения во взаимодействие с пучком, наряду с основным СВЧ-сигналом, электромагнитных полей высших гармоник при определенных соотношениях мощностей и абсолютном синхронизме. В этой работе представлены предварительные результаты изучения возможности многочастотной генерации высокочастотной мощности в пролетных клистронах, содержащих дополнительные выходные системы на высшие гармоники, установленные за основным выходным резонатором по ходу пучка. Физическое обоснование предложения основано на использовании эффекта перегруппировки протяженных электронных сгустков тормозящими СВЧ-полями большой амплитуды. Приводится описание предваряющих экспериментальных результатов, краткое описание программы расчетов АРСЕНАЛ-МГУ и результаты моделирования.

ЕФЕКТ ЗБУДЖЕННЯ ВИСОКОЧАСТОТНОЇ ПОТУЖНОСТІ НА КРАТНИХ ЧАСТОТАХ В ПРИЛАДАХ О-ТИПУ

А.М. Довбня, Ю.Д. Тур, В.Є. Родякін, А.Н. Сандалов

Необхідність створення НВЧ-джерел, працюючих в режимі одночасної генерації потужності на кратних частотах, зокрема обумовлюється задачами фізики прискорювачів, такими як пригнічення ефекту зростання емітансу в інжекторах з ВЧ-гарматами та підвищення граничного прискореного заряду. Це може бути реалізовано шляхом включення до взаємодії з пучком, урівні з основним НВЧ-сигналом, електромагнітних полів на вищих гармоніках при відповідних співвідношеннях амплітуд та абсолютнім синхронізмі. В цій роботі приведені попередні результати вивчення спроможності багаточастотної генерації високочастотної потужності в пролітних клістронах, які містять додаткові вихідні системи на вищих гармоніках, розташованих по ходу пучка за основною. Фізичне обґрунтування пропозиції основане на використанні ефекту перегрупування протяжних електронних згустків при їх взаємодії з гальмуючими НВЧ-полями великої амплітуди. Приведено опис передуючих експериментальних результатів, стислий опис розрахункової програми та результатів моделювання.