Simulation of High-Efficiency Klystrons with the COM and CSM bunching

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Abstract: *the two types of high effective bunching in powerful klystrons are discussed. The first bunching type, named COM, is intended for standard klystron structure with first harmonic cavities only. The second bunching type, named CSM, is realized in klystron structures which includes cavities of second and third harmonics. Both bunching types allow to reach the klystron efficiency up to 90%.*

Keywords: *klystron, efficiency, bunching method, simulation***.**

I. Introduction

The method for the synthesis of klystrons with an efficiency of 80-90% was developed in the serial of works, such as [1-4]. In these works, it was shown that to achieve efficiency values of more than 80%, it is necessary to achieve high saturation of the bunch at the entrance to the output gap. Quantitatively, the saturation is defined as the proportion of electrons of the period trapped in the bunch of a fixed length. To obtain an electronic efficiency of 90% requires a saturation of at least 0.97 for $\pi/2$ bunch.

To achieve these saturation values is necessary to provide the combination of small displacements of the central particles (core) of the bunch with a large displacement of the peripheral particles (anti-bunch).

Most of the results presented below are obtained by the KlypWin [1, 2] code.

II. Stage-by-stage optimization and COM-bunching.

It was shown in [1,2] that a bunch with a saturation close to 100% can be obtained by the COM-bunching (Core Oscillation Method), which consists in the fact that the central particles of the bunch oscillate, and the peripheral particles monotonically approach the bunch.

It is shown in [1] that the most important input integral dimensionless parameter affecting the character of bunching is the Lumped Bunching Length (LBL) [2].

The optimal value of LBL for COM-mode depends on the number of stages almost linearly in accordance with the approximation dependence $l_{\Omega,opt} = k \cdot (n-1)$, where *n*- the number of stages (of cavities), and *k* is within limits from 1.15 to 1.30.

The COM bunching process is obtained by the stage-by-stage optimization process of klystron of the standard configuration (all cavities work on the first harmonic). The optimization is carried out by the method of macro-steps [4] on the maximum number of parameters of group "B" [2,4], in a wide range of their changes.

In accordance with macro-steps method, the two-stage klystron is optimized first to find for it the optimal value of LBL corresponding to the maximum value of efficiency. The number of stages is then increased by one and the procedure is repeated several times. Before the every optimization to increase the number of stages n>2 from n to n+1 the second stage duplicates. This procedure allows you to find the optimal number of stages corresponding to the saturation of the efficiency.

Let us consider the results of stage-by-stage optimization of various devices.

The first stage-by-stage optimization process was carried out in [1] for a seven-beam klystron of the decimeter range with a beam power of 42kw based on an existing television prototype.

We performed a similar optimization for the 42-beam klystron at a frequency of 990 MHz with a beam power of 8.5 MW and for 40 beams klystron with a beam power of 10 MW at a frequency of 2.86 MHz. Both klystrons were modeled on real prototypes designed for powering accelerators [4].

The process and the results of stage-by-stage optimization of the third device is shown in Fig. 1.

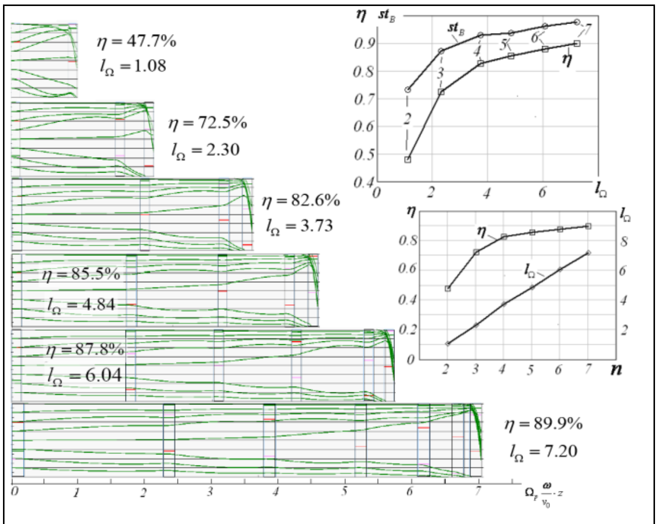

Fig.1. Process of stage-by-stage optimization: η - efficiency, l_Ω*-LBL,* st_B*-bunch saturation, n – number of cavities (stages).*

Saturation of efficiency is achieved at 7-cavities klystron with the value about 90%.

A comparative analysis of the dependence of efficiency and optimal LBL vs the number of stages is shown in Fig. 2, where “1” is the 30 kW L-band CW klystron with 7 beams, “2” is the 5 MW 42 beams L-band pulse klystron, “3” is the 10 MW 40 beams S-band pulse klystron (see [4]). Despite the strong difference of klystrons, these curves are very similar.

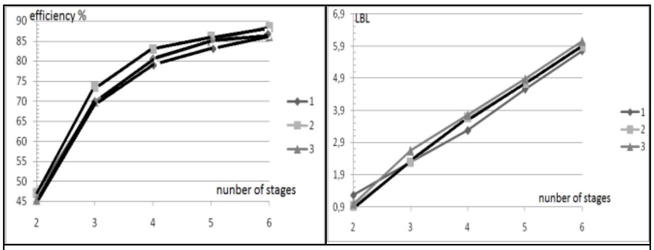

Fig. 2. Dependences of efficiencies (left) and LBL (right) vs number of stages for three different klystrons.

III. Embedding Procedure and CSM Bunching

The next task we considered is to maximize the efficiency at a fixed length of the device. Take as a basis the optimal three-cavity COM-klystron with an efficiency of about 70% and consider the change in gain and efficiency when adding additional cavities between the existing ones. The process of such addition of cavities was called «embedding» or «inset».

Consider first the embedding the cavities of the first harmonic only. This process increases the gain from 28 dB to 43 dB, but practically does not affect the efficiency. The embedding of second harmonic cavities allows obtaining efficiency about 80%.

Only the embedding of the cavity of the third harmonic allows to achieve an efficiency of 85% and higher. Moreover, an increase in the efficiency of up to 90% is obtained even with the use of only one third harmonic cavity.

The bunching process of the synthesized CSM-klystron with an efficiency of 90% is shown in Fig.3. In contrast to the COM mode any oscillations of the core of the bunch are not observed: all particles of a bunch are shifting to the center of the bunch almost monotonically, and this

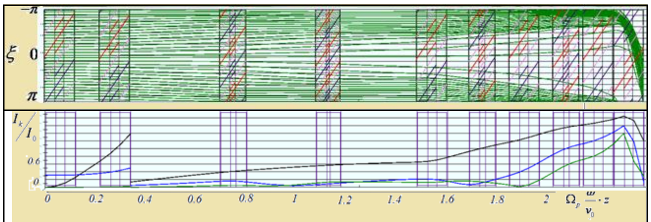

Fig. 3. Phase trajectories (top) and current harmonics (bottom) of CSM-klystron with configuration «1123121211» and with efficiency 90%

displacement is terminated at a some distance from the center of bunch, i.e. the core of a bunch gradually "stabilizes" itself during forming (Fig.3). This character of the bunching process led to the name "Core Stabilization Method" or CSM.

Note the second harmonic cavity began to use in klystron since 70s of 20th century. Structures with two and three second harmonic cavities first investigated I. Gusilov, he used term "BAC" for such a bunchind mechanism [5]. The third harmonic cavity in klystron buncher was first investigated apparently by I. Syrathev and C. Marrelly. They initially used the term "F-tube" [6]. We propose to use the more general term CSM for all these cases.

IV. Analysis of CSM Bunching Mechanism

The explanation of the CSM-bunching mechanism is that the action of the microwave field of harmonic cavities turns out to be multidirectional in the region of the bunch core and unidirectional (unbunching) in the region of the anti-bunch. The result of the these combined effects creates a zone of stabilization in the region of the core of the bunch and area of strong unbunching in the anti-bunch (Fig.4). If the particles of the bunch core fall into the stabilization zone with the velocity modulation of zero, then they almost do not change their speed further (core of bunch stabilizes).

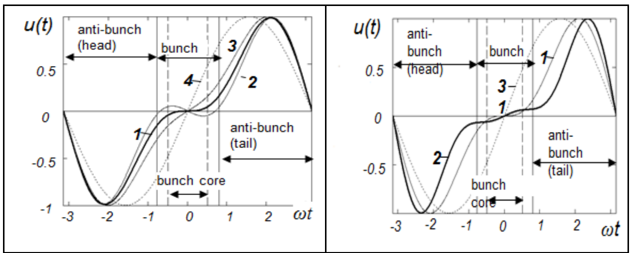

Fig. 4. Sum of two (left) and three (right) harmonics, providing the stabilization zone for CSM process.

V. Summary

The two bunching mechanisms to achieve the extremal values of klystron efficiency are considered. The first mechanism, called COM, can be realized by the "stage-by-stage" way of optimization. The second mechanism, called SCM, can be realized by the "embedding" way of optimization. Both ways lead to 90% efficiency for the different klystron prototypes.

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