Influence of the Synchronism Detuning on Single Mode Operation of Two-Channel Planar FEM

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***Abstract*— Paper presents experimental results on spectral measurements of high-power 4-mm radiation generated by a two-channel planar free electron maser (FEM) at variation of electron energy and magnetic field of undulator. It was shown that the single mode operation of the FEM is achieved at satisfying the condition of the undulator synchronism shifted to the detuning, predicted by theory for maximum of the electron efficiency.**

I. Introduction

Two-dimensional (2-D) distributed feedback gives the opportunity to construct generators of a coherent electromagnetic wave flux with cross-section sizes, highly exceeding the radiation wavelength. We study such mechanism of spatial synchronization of electromagnetic oscillations for the case of a planar free electron maser at the ELMI-device (BINP, Novosibirsk) [1]. First single mode single frequency generation of 4-mm wave in one-channel FEM at this device was obtained in 2006 [2]. This operation mode had the radiation power of 10 MW at the pulse duration of 300 ns. In recent experiments we have demonstrated the possibility of synchronous generation of radiation pulses in two weakly coupled channels of the FEM-oscillator with the following parameters: the generated frequency 75 GHz at a spectrum width of ~20 MHz, the pulse duration ~200 ns and the typical power from both channels of ~30–50 MW [3]. The aim of the current investigations is to find the regions of variation for the electron energy, the undulator and the guiding magnetic fields, in which the single mode operation of such FEM should be achieved.

II. Results

The experiments were carried out at the FEM-oscillator which consists of two weakly coupled channels driven by two sheet electron beams (1 MeV/ 1 kA/ 5 μs/ 0.4×7cm) (Fig. 1). Each channel contains a hybrid two-mirror cavity composed of upstream 2-D and downstream 1-D Bragg reflectors. The transverse sizes of the cavity are about 2.5×25 wavelength of the radiation.

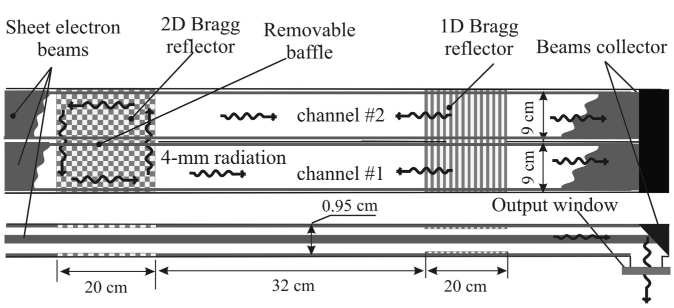

Fig. 1. Schematic of two-channel FEM

In the experiments baffle between 2-D reflectors was not removed so the channels were separated. Some weak coupling due to the wave diffraction was only in the exit area near the beam collectors.

Spectral properties of 1D and 2D planar Bragg reflectors are presented in Fig. 2. Except the main band 74.5–75.5 GHz where the reflectivities of the fundamental FEM-operating wave H_{10} are overlapping, the additional parasitic band 77–79 GHz is detected. Its existence is determined by the transformation of H_{10} wave to parasitic E_{12} on 1-D thread (blue curve in Fig. 2 corresponds to the simulated coefficient of transformation). The reverse transformation on 2-D corrugated surface is possible due to imperfections of the thread. The wave E_{12} is not directly measured in “cold” tests, that’s why there is some inconsistency with simulation results.

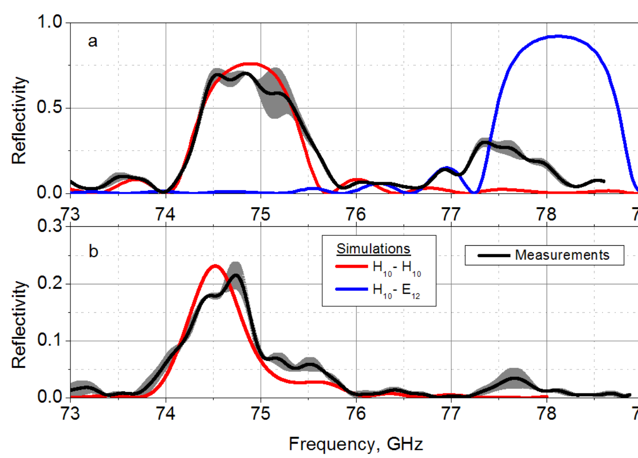

Fig. 2. Coefficient of reflection for downstream 1-D (a) and upstream 2-D (b) planar Bragg reflectors (the grey stripe around the black line shows the errors of the measurements)

In accordance with positions of the reflection bands two distinct groups of high-*Q* longitudinal modes were observed in “cold” tests of the cavity selective properties and in “hot” experiments with FEM. These groups are located near 75 and 78 GHz with inter-mode frequency intervals 300–400 MHz that corresponds to the effective cavity length 40–50 cm.

In the “hot” experiments we measured the radiation spectrum by heterodyne diagnostics at varying the accelerator diode voltage and the strength of the undulator magnetic field components. In most shots we observed the pulses of single-frequency generation with excitation of most high-Q modes with the frequencies 74.6 and 77.7 GHz. The Fig. 3 demonstrates two distribution functions (Gauss approximations of experimental data) for the probability to obtain single frequency emission at least from one of the FEM channels dependent on the average diode voltage during the mm-wave pulse.

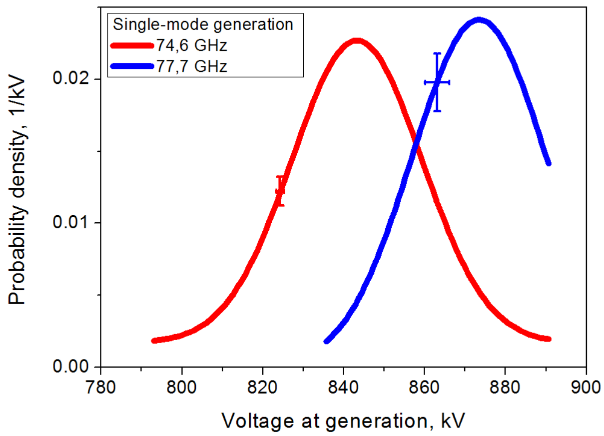

Fig. 3. Statistics on shots with single frequency generation at 74.6 and 77.7 GHz at least in one channel of the FEM.

As it is seen the obtained mean values of distribution functions are close to 840 kV and 875 kV respectively with dispersion about of 20 kV. The values of averaged longitudinal beta $\beta_{||}$=0.914 and 0.918 calculated for the motion of the electrons with specified energies in the magnetic field of the undulator ($B_{\perp} = 0.138\,\text{T}$ and $B_{||} = 1.14\,\text{T}$, undulator period – 4 cm), closely satisfy the undulator resonance condition:

$$\beta_{||} = \frac{\omega}{c} \cdot \frac{(1 - C \cdot \Delta)}{h + h_u}$$

at the value of $C \cdot \Delta$ equal to -(5÷6)·10^{-3}, where ω – the angular frequency of the radiation, C – Pierce parameter, Δ – the detuning from the undulator synchronism, and h and h_u – the wave numbers of the generated mm-wave and the undulator magnetic field. The same value of $C \cdot \Delta$ is predicted by the theory [4] for the parameters of our experiment at the maximum of the electron efficiency. This relation allows to predict the parameters of experiment at which single-mode single-frequency operation of the planar FEM is the most probable.

It should be noted that the transitions (jumps) from one high-Q mode to another were also observed in the experiments at the smooth decrease of the diode voltage in the range 870–840 kV.

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