JINR ACTIVITY IN MICROWAVE SOURCES FOR FUTURE LINEAR COLLIDERS[*]

A.K. Kaminsky, A.V. Elzhov, I.N. Ivanov, V.I. Kazacha, V.V. Kosukhin,
E.A. Perelstein, S.N. Sedykh, A.P. Sergeev, JINR, Dubna, Russia
G.G. Denisov, N.S. Ginzburg, N.Yu. Peskov, A.S. Sergeev, IAP RAS, Nizhny Novgorod, Russia
E.M. Laziev, YerPhI, Yerevan, Armenia

Abstract

Results of theoretical and experimental studies of the microwave sources on the base of the linac LIU-3000 (JINR, Dubna) are presented. In particular, FEM-oscillator with reversed guide magnetic field and Bragg resonator as well as an electron beam buncher in the two-beam accelerator (TBA) driver were studied.

1 INTRODUCTION

The aim of the work carried out during recent few years at JINR (Dubna) in collaboration with IAP RAS (N.Novgorod) and YerPhI (Yerevan, Armenia) is the development of powerful narrow-band microwave sources for possible application in linear colliders of next generation. This work includes theoretical analysis, simulations and experiments with the generators at the frequency band near 30 GHz that corresponds to the CLIC Transfer Structure requirements.

A high-efficiency single-mode free-electron maser (FEM) have been investigated. The main feature of this oscillator is the use of a reversed guide magnetic field and a Bragg resonator as a selective feedback arrangement. As a result of the experiments at a frequency of 30.7 GHz the output power of a 50 MW and the highest efficiency of 35% were reached [1]. The achieved output power and radiation spectrum bandwidth allow one to consider the FEM-oscillator as an RF source for testing TBA high-gradient accelerating structures. Present paper is devoted to studies of the Bragg FEM-oscillator dynamics and discussing the possibility of precise frequency tuning of the oscillator. It is important for testing TBA high-gradient accelerating structures when a FEM-oscillator is used as a RF power-source.

Experiments directed on the development of a novel scheme of TBA driver [2] are also carried out. In this scheme bunched beam transportation occurs in the accompanying enhanced microwave that provides the RF phase stability along the whole driver. Progress in the TWT-amplifier experiments is presented.

2 PRECISE FREQUENCY TUNING IN FEM-OSCILLATOR

Several schemes of FEM-oscillators with reversed guide magnetic field and various types of Bragg resonators were investigated experimentally as well as theoretically last time [1,3]. Single-mode or multi-mode regimes of the FEM operation with the record efficiency of ~ 25-35% were demonstrated in these schemes. It was showed theoretically [4] that a FEM oscillator using a Bragg resonator with a step of the corrugation phase is capable of providing precise frequency tuning by varying the phase shift between the Bragg reflectors. This resonator possesses only one eigenmode inside the zone of effective Bragg reflection with the Q-factor much greater than the Q-factors of other modes positioned outside the effective Bragg reflection zone [4].

A numerical simulation of the beam-wave interaction in FEM with such resonator was fulfilled for three values of the step of the corrugation phase (Fig. 1).

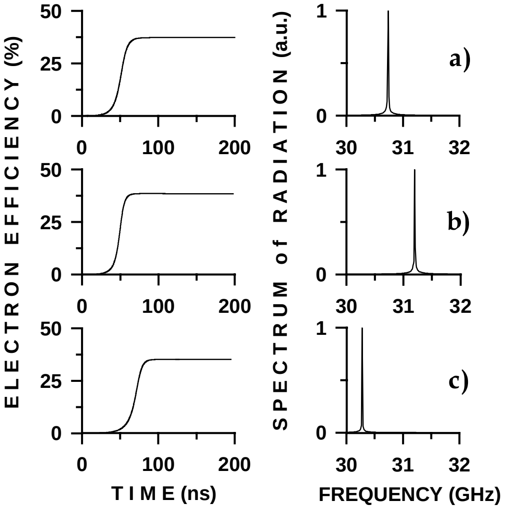

Figure 1: Simulation results for dynamics in FEM oscillator for different values of the corrugation phase shift φ: a) φ = π; b) φ = π/2; c) φ = 3π/2.

This work is supported by grants №№ 00-02-17519, 00-02-17232, 98-02-17685 of Russian Foundation for Basic Research and the INTAS grant № 97-32041

One can see from Fig. 1 that ranging the phase shift from $\pi/2$ to $3\pi/2$ can maintain the same high efficiency level.

New experimental data on the frequency tuning of the FEM oscillator and their comparing with the simulation results are presented below. The scheme of the setup was similar to one used in [1,4]. The linac energy has been risen up to 1.0 MeV. The electron beam currents before the injection into the FEM waveguide and at its output were measured to be of 200 A and 150-180 A respectively. The beam pulse duration was about 250 ns.

The Bragg resonator consisted of two contiguous corrugated waveguides 26 cm and 13 cm long with the bore diameter 19 mm. The period of the corrugation and its depth were equal to 5.4 mm and 0.6 mm respectively.

Changing of the length and profile of the first short waveguide corrugation was carried out to adjust the corrugating phase step. The power measurements were carried out with the help of two pulse crystal microwave detectors (measuring and monitor one). The narrow-band filter set in the measuring detector scheme was used for the RF frequency defining, in contrast to the cut-off filters in earlier experiments. The measurable frequency range was from 25 to 38 GHz. The error in the frequency measurement was about 0.2 GHz.

The output RF power in the frequency range 29-31 GHz (H_{11} mode) was measured to be about 25-35 MW. The power level was not optimized. The radiation pulse duration was equal to 70-130 ns. The electron beam bunching corresponding to the frequency of 30.7 GHz was registered with the help of streak camera as well as in the TWT experiment (see Section 3).

The results of the frequency tuning measurements are given in Fig.2.

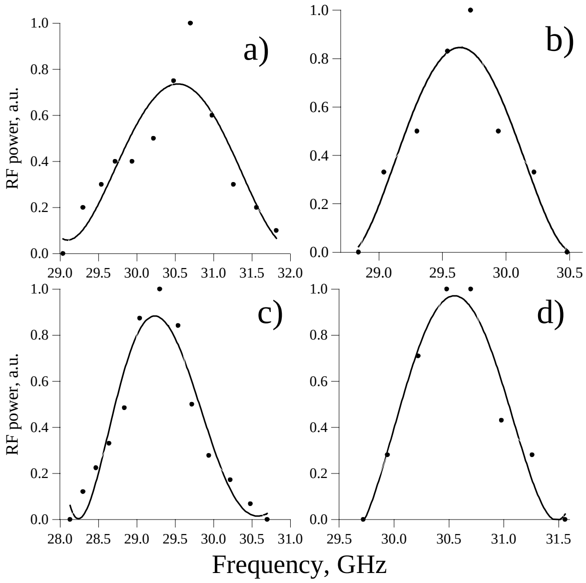

Figure 2: Output RF power versus the frequency for different values of the corrugation phase shift φ: a,b) $\varphi = \pi$; c) $\varphi = 3\pi/2$; d) $\varphi = \pi/2$.

Figs. 2a,b correspond to the phase step π between the Bragg reflectors and were obtained at wiggler field values of 1550 Gs and 1460 Gs respectively. The guide magnetic field was equal to –2060 Gs. Fig. 2a corresponds to the central mode of the Bragg resonator, Fig. 2b – to the side mode, i.e. mode shifted on the half of width of the resonator reflection band. Its size is the same that the difference between the frequencies shown in Fig.1b and 1c. One can see that the measured values of the central frequency and frequency shift coincide with a good precision with simulation results though the measured RF power spectral distributions have rather large frequency sizes. Measurement of the central FEM-oscillator frequency in the case of the phase shift $3\pi/2$ (Fig. 2c) yields the value close to the measured one for the side mode for the phase shift π (Fig. 2b). When the phase shift was equal to $\pi/2$ (Fig. 2d) the oscillator was not started up at the central frequency though the generation on the shifted downward frequency was observed.

In our simulations the oscillator parameters were chosen so that the single-mode generation occurred already at the linear stage of the FEM operation. However in the experiment both the multi-mode or single regimes of the generation at the linear stage were possible.

3 INVESTIGATION OF THE BEAM BUNCHING IN A TWT AMPLIFIER

A novel scheme of two-beam accelerator driver is currently studied at JINR [2]. In this scheme the electron beam is accompanied by a synchronous RF wave along the whole driver. It should provide the high spatial phase stability of the output radiation. The beam bunching and the microwave amplification may be realized on the base of the traveling wave tube (TWT) amplifier**.**

It had the length of ~ 45 cm and main radius 9.1 mm. The scheme of the experiments is shown in Fig. 3.

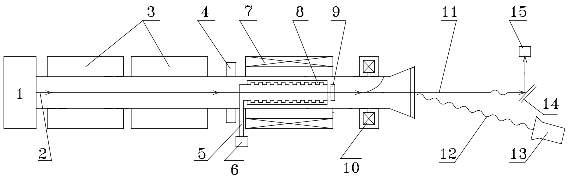

Figure 3: Scheme of the experiment: 1) electron gun; 2) electron beam; 3) accelerating sections; 4) tuning magnetic lens; 5) microwave transmission line; 6) magnetron; 7) solenoid; 8) corrugated cylindrical waveguide; 9) quartz strip; 10) deflecting magnets; 11) optical Cherenkov radiation; 12) microwave radiation; 13) RF detector; 14) optical mirror; 15) streak camera IMACON-500.

The slow electric type wave E_{01} of the oversize cylindrical waveguide with corrugated wall was chosen as an operating wave. The phase wave velocity value $\beta_{ph} = 0.86$ at the operating magnetron frequency $f = 36.4$ GHz was close to the electron velocity.

The entrance signal was transmitted into the operating waveguide (8) from the magnetron (6) with the help of the quasi-optical system previously used in [5]. The microwave losses from the magnetron to the TWT input were ~ 13 dB. The electron beam parameters were as follows: 660 keV, 200 A, 200 ns. The uniform guide field of 1-3 kGs was used in these experiments and the input beam radius of ~ 5 mm was tuned to reach the maximal of the output RF power.

The measured maximum of the amplified microwave power was equal to ~ 5 MW with the gain ~ 30 dB. Coincidence with the corresponding calculations was rather good.

We used a quartz strip with the thickness of 3 mm, width of 3 mm and refractive index $n = 1.46$ for bunch dimension measurements. The target was placed on the accelerator axis at the distance ~ 80 mm from the TWT output. The electron bunches moved from the TWT exit to the quartz strip accompanied by the microwave, passed through the strip and generated Cherenkov radiation which was taken out through the vacuum window. Hereupon Cherenkov radiation was directed to the input slit of the streak camera with the help of the optical mirror. The registered set of bunches is shown in Fig. 4. Sweep speed is equal to 13.3 ps/mm. The distance between the bunches was measured to be about 8.2 mm.

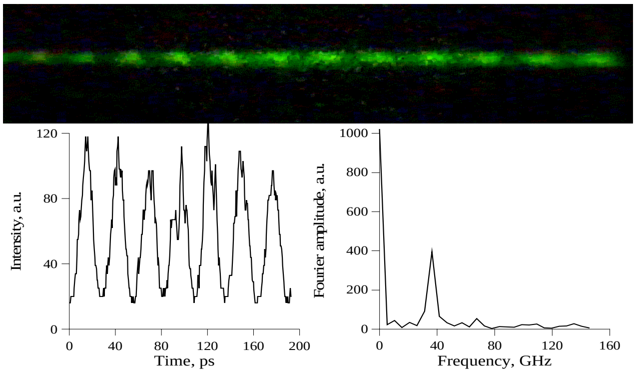

Figure 4: Temporal profile of the bunched electron beam recorded by the streak camera (top). Digitized intensity of streak-camera image (in arbitrary units) plotted versus time (bottom, left). The corresponding Fourier spectrum (bottom, right).

We observed a significant peak at a frequency close to 36.4 GHz. The experimental bunching parameter was defined as the ratio of the Fourier components at 36.4 GHz and zero frequency, respectively. The measured value was ~ 0.4. It is close to the value obtained in [6] at the beam energy of 2.2 MeV.

The numerical simulation shows that the beam bunching completely disappears at ~ 4 cm after the TWT output if the beam is not accompanied by the amplified microwave. At the same time, the fulfilled experiments confirmed that the electron bunches keep high level of the bunching parameter at the distance ~ 10 cm from the TWT exit being accompanied by the amplified microwave.

4 CONCLUSIONS

The possibility of frequency tuning for high-efficiency FEM oscillator using a Bragg resonator with a step of corrugation phase was proved experimentally. The measured generation frequencies and the range of the frequency tuning are in a good agreement with the results of the computer simulation.

The electron beam bunching was registered with the help of Cherenkov radiation in the FEM oscillator and the TWT amplifier at the frequencies of 30.7 and 36.4 GHz respectively.

The first set of experiments fulfilled with the TWT buncher showed that the electron beam, accelerated in LIU-3000 allow us to obtain the necessary level of the amplified microwave power (~ 5 MW) and high enough bunching parameter (~ 0.4) for carrying on further experiments with the TBA driver scheme.

REFERENCES

[1] A.V. Elzhov, N.S. Ginzburg, I.N. Ivanov et al., “Recent Experiments on Free-Electron Maser for Two-Beam Accelerators”, HEACC’98, Dubna, September 1998, p. 160.

[2] A.V. Elzhov, A.A. Kaminsky, A.K. Kaminsky et al., “New Scheme of Two Beam Accelerator Driver Based on Linear Induction Accelerator”, EPAC’98 , Stockholm, June 1998, p. 472.

[3] A.K. Kaminsky, A.A. Kaminsky, S.N. Sedykh et al., “Efficiency Optimisation of the JINR Narrow-Band Millimeter Wavelength FEL-Oscillator”, FEL’96, Rome, August 1996, p. II-81.

[4] C.A. Goldenberg, A.A. Kaminsky, A.K. Kaminsky et al., “FEL-oscillator for Feeding of High-Gradient Accelerating Structure”, PAC'99, New York, 1999, p. 1055.

[5] E.B. Abubakirov, O.V. Arkhipov, L.V. Bobyleva et al. “Generation and Acceleration of High-Current Annular Electron Beam in Linear Induction Accelerator and Microwave Power from Cherenkov TWT”, EPAC’90, Nice, 1990, p. 34.

[6] J. Gardelle, T. Lefevre, G. Marchese et al., “Experimental Coupling of 35 GHz RF-Cavities with an Intense Bunched Electron Beam”, EPAC’98, Stockholm, June 1998, p. 463.